Appendix G
Electric and Magnetic Fields

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- Assessment of Research Regarding EMF and Health and Environmental Effects
- Electrical Effects

McNARY – JOHN DAY TRANSMISSION-LINE PROJECT

ASSESSMENT OF RESEARCH REGARDING EMF AND HEALTH AND ENVIRONMENTAL EFFECTS

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ASSESSMENT OF RESEARCH REGARDING EMF AND HEALTH AND ENVIRONMENTAL EFFECTS

1.0 Introduction

Over the last 20 years, research has been conducted in the United States and around the world to examine whether exposures to electric and magnetic fields (EMF) at 50/60 Hertz (Hz) from electric power lines are a cause of cancer or adversely affect human health. The research included epidemiology studies that suggested a link with childhood leukemia for some types of exposures, as well as other epidemiology studies that did not; it also included lifetime animal studies, which showed no evidence of adverse health effects. Comprehensive reviews of the research conducted by governmental and scientific agencies in the U.S. and in the United Kingdom (UK) had examined the research, and did not find a basis for imposing additional restrictions (NIEHS, 1999; IEE, 2000).

The Bonneville Power Administration (BPA) requested that Exponent update the BPA on research on EMF and health in relation to exposures that might occur near the McNary – John Day Transmission Line Project. This update concentrates on recent major research studies to explain how they contribute to the assessment of effects of EMF on health (Section 2). The focus is on both epidemiologic and laboratory research, because these research approaches provide different and complementary information for determining whether an environmental exposure can affect human health. Section 3, Ecological Research, reviews studies of potential effects of EMF on plants and animals in the natural environment. This update includes studies of residential or environmental exposures to EMF and health effects that became available in 2001 (through November).

2.0 Health

2.1 The NIEHS Report and Research Program

In 1998, the NIEHS completed a comprehensive review of the scientific research on health effects of EMF. The NIEHS had been managing a research program that Congress funded in 1992 in response to questions regarding exposure to EMF from power sources. The program was known as the RAPID Program (Research and Public Information Dissemination Program). The NIEHS convened a panel of scientists (the "Working Group") to review and evaluate the RAPID Program research and other research. Their report, *Assessment of Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields,* was completed in July 1998 (NIEHS, 1998).

The director of the NIEHS prepared a health risk assessment of EMF and submitted his report to Congress in June 1999 (NIEHS, 1999). Experts at NIEHS, who had considered the previous Working Group report, reports from four technical workshops, and research that became available after June 1998, concluded as follows:

> The scientific evidence suggesting that ELF-EMF [extremely low frequency-electric and magnetic field] exposures pose any health risk is weak. The strongest evidence for health effects comes from associations observed in human populations with two forms of cancer: childhood leukemia and chronic lymphocytic leukemia in occupationally exposed

> adults. . . . In contrast, the mechanistic studies and animal toxicology literature fail to demonstrate any consistent pattern. . . . No indication of increased leukemias in experimental animals has been observed. . . . The lack of consistent, positive findings in animal or mechanistic studies weakens the belief that this association is actually due to ELF-EMF, but it cannot completely discount the epidemiology findings. . . . The NIEHS does not believe that other cancers or other non-cancer health outcomes provide sufficient evidence of a risk to currently warrant concern (NIEHS, 1999: 9-10).

Although the results of the RAPID research are described in some detail in the 1998 report, many of the studies had not been published in the peer-reviewed literature. Recognizing the need to have these results reviewed and considered for publication, the NIEHS arranged for a special edition of the journal *Radiation Research* (Radiation Research, 153[5], 2000) to be devoted to this topic.[1]

2.2 Update of Research Related to Cancer

This update includes studies of residential or occupational exposures to EMF and leukemia that became available through November 2001, including several epidemiology studies of childhood cancer and meta-analyses. The California Department of Health Services (CDHS) conducted a workshop in 1999 to discuss epidemiologic research on EMF and health. The reports presented at this workshop were published in January 2001 as a supplement to the journal, *Bioelectromagnetics*. Many of the papers were technical discussions of methodology issues in epidemiologic studies of EMF, including discussions of how to better understand the conflicting results reported in previous studies (Neutra and Del Pizzo, 2001). For example, one study evaluates the extent to which systematic errors (known in epidemiology as selection bias or information bias) occurred in EMF studies, and if those errors occurred, whether the effect on results could be evaluated (Wartenberg, 2001a). Other researchers discuss epidemiologic approaches to study how possible confounding factors, such as the age and type of home and traffic density, might affect the interpretation of studies of EMF and childhood cancer (Langholz, 2001; Reynolds et al., 2001).

For this update, we reviewed epidemiology and laboratory studies of cancer and reproduction. Several of the studies are "meta-analyses," an approach that incorporates statistical methods to analyze differences among studies and aggregate the results of smaller studies. The sections below include a review of meta-analyses of the studies of childhood leukemia, and a meta-analysis of studies of breast cancer in adults (Erren, 2001).

2.2.1 Epidemiology Studies of Children

The question of power lines and childhood cancer has been based on the assumption that the relevant exposure associated with power lines is the magnetic field, rather than the electric field. This assumption rests on the fact that electric fields are shielded from the interior of homes (where people spend the vast majority of their time) by walls and vegetation, while magnetic fields are not. The magnetic field in the vicinity of a power line results from the flow of current; higher currents result in higher levels of magnetic fields.

Epidemiologic studies report results in the form of statistical associations. The term "statistical association" is used to describe the tendency of two things to be linked or to vary in the same way, such

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[1] See, for instance, the articles cited in the **List of References** under Balcer-Kubiczek, Boorman, Loberg, and Ryan.

as level of exposure and occurrence of disease. However, statistical associations are not automatically an indication of cause and effect, because the interpretation of numerical information depends on the context, including (for example) the nature of what is being studied, the source of the data, how the data were collected, and the size of the study. The larger studies and more powerful studies of EMF have not reported convincing statistical associations between power lines and childhood leukemia (e.g., Linet et al., 1997; McBride et al., 1999; UKCCS, 1999). Despite the larger sample size, these studies usually had a limited number of cases exposed over 2 or 3 milligauss (mG).

Epidemiology Studies

The following discussion briefly describes major studies.

- A study from Germany included 514 children with leukemia and 1,301 control children (Schuz et al., 2001). Measurements of magnetic-field intensity (50 Hz) were taken for 24 hours in each child's bedroom. The results were calculated separately for daytime or nighttime levels in the bedroom, rather than for a child's overall 24-hour exposure. The authors report an association with leukemia for mean daytime magnetic-field exposures that might have been due to chance. They reported an association between mean nighttime magnetic-field levels and leukemia for the highest exposed group (4 mG or higher; 9 cases). The assessment of exposure by mean field levels in the bedroom did not link magnetic-field levels to any specific source. The authors note in their conclusions that " . . . fewer than one-third of all stronger magnetic fields were caused by high-voltage powerlines . . . . " (Schuz et al., 2001:734).

  Several aspects of the study detract from the validity of the results: the estimate included a broad margin of error because only a small number of cases was exposed at the higher levels, and many eligible cases and controls did not participate, which means that the responders may not represent the population and results could be biased. Another concern is that these magnetic-field measurements were taken in 1997, long after the relevant exposure period for cases diagnosed in 1990-1994. Magnetic-field levels may have changed over time, as electricity usage changed.

- A study from British Columbia, Canada, included 462 children who had been diagnosed with leukemia and an equal number of children without leukemia for comparison (McBride et al., 1999). Magnetic-field exposure was assessed for each of the children in several ways: personal monitors were worn in a backpack for 48 hours, a monitor took measurements in the bedroom for 24 hours, the wiring outside the house was rated by potential exposure level (wire codes), and measurements were taken around the outside perimeter of the homes. (Wire codes are a method of estimating relative exposure intensity based on the configuration of the power lines.) Regardless of the method used to estimate magnetic-field exposure, the magnetic-field exposure of children who had leukemia was not greater than that of the children in the comparison group.

- A study conducted in Ontario, Canada reported on the magnetic-field exposure of a smaller group of children than in other recent studies (Green et al., 1999a). No increased risk estimates were found with the average magnetic fields in the bedroom or the interior, or with any of the three methods of estimating exposure from wire-configuration codes. A still smaller group of 88 children with leukemia and their controls wore personal monitors to measure magnetic fields (Green et al., 1999b). Associations with magnetic fields were reported in some of the analyses, but most of the risk estimates had a broad margin of error, and major methodological problems in the study preclude any clear interpretation of the findings.

- The United Kingdom Childhood Cancer Study, the largest study to date, included a total of 1073 childhood leukemia cases (UKCCS, 1999). Exposure was assessed by spot measurements in the home (bedroom and family room) and school, and summarized by averaging these over time. No evidence was found to support the idea of an increased risk of leukemia from exposures to magnetic fields inside or outside of the home.

- The UKCCS investigators had obtained magnetic-field measurements on only a portion of the childhood cancer cases in their study (UKCCS, 1999). To obtain additional information, they used a method to assess exposure to magnetic fields without entering homes; they were thus able to analyze 1331 child leukemia cases (UKCCS, 2000). For these children, they measured distances to power lines and substations. This information was used to calculate the magnetic field from these external field sources, based on power-line characteristics related to production of magnetic fields. The results of the second UKCCS study showed no evidence for an association with leukemia for magnetic fields calculated to be between 1 mG and 2 mG, 2 mG and 4 mG, or 4 mG or greater at the residence, in contrast to the weak association reported for measured fields of 4 mG or greater in the first report (UKCCS, 1999).

Researchers have proposed that the associations that are sometimes reported between childhood leukemia and power lines might be due to other factors that can confound (other risk factors for disease that may distort the analysis) the analysis. One example is heavy traffic, which may occur near power lines and which can increase the levels of potentially carcinogenic chemicals in the area. Earlier studies had reported associations between traffic density and childhood cancer (Savitz et al., 1988). If power lines were more common in areas that had higher traffic density, then the increased air pollution might explain an association between power lines and childhood cancer. However, more recent studies seem to eliminate this possibility. In a study of 90 cases of childhood leukemia, Reynolds et al. (2001) found no evidence of an association with traffic density. In a larger study that included 986 cases of childhood leukemia, no association was found with high traffic-density exposure during pregnancy or childhood (Raaschou-Nielsen et al., 2001).

Meta-analyses of Studies of Leukemia

Recently, researchers re-analyzed the data from previous epidemiology studies of magnetic fields and childhood leukemia (Ahlbom et al., 2000; Greenland et al., 2000). The researchers pooled the data on individuals from each of the studies, creating a study with a larger number of subjects and therefore greater statistical power than any single study. A pooled analysis is preferable to other types of meta-analyses in which the results from several studies are combined from grouped data obtained from the published studies. These analyses focused on studies that assessed exposure to magnetic fields using 24-hour measurements or calculations based on the characteristics of the power lines and current load. Both Ahlbom et al. and Greenland et al. used exposure categories of <1 mG (<0.1 microtesla [μT]) as a reference category. The statistical results of these analyses can be summarized as follows:

- The pooled analyses provided no indication that wire codes are more strongly associated with leukemia than measured fields.

- Pooling these data corroborates an absence of an association between childhood leukemia and magnetic fields for exposures below 3 mG (0.3 μT).

- Pooling these data results in a statistical association with leukemia for exposures greater than 3-4 mG (0.3 or 0.4 μT).

The authors are appropriately cautious in the interpretation of their analyses, and they clearly identify the limitations in their evaluation of the original studies. Magnetic fields above 3 mG (0.3 μT) in residences are estimated to be rather rare, about 3% in the U.S. (Zaffanella, 1993). Limitations include sparse data (few cases) to adequately characterize a relationship between magnetic fields and leukemia, uncertainties related to pooling different magnetic-field measures without evidence that all of the measures are comparable, and the incomplete and limited data on important confounders such as housing type and traffic density.

A meta-analysis of the data from epidemiologic studies of childhood leukemia studies was presented at the California Workshop and recently published (Wartenberg, 2001b). This meta-analysis did not have the advantage of obtaining and pooling the data on all of the individuals in the studies, unlike those published before it (Ahlbom et al., 2000; Greenland et al., 2000). Instead of using individual data, Wartenberg (2001b) used an approach that extracted the published results, reported as grouped data from several published studies. He used 19 studies overall, after excluding 7 studies that had insufficient data on individuals or deficiencies in the exposure assessment data. He reported a weak association for a) “proximity to electrical facilities” based on wire codes or distance, and b) magnetic-field level over 2 mG, based on either calculations from wiring and loading characteristics (if available) or on spot magnetic-field measurements. The results show more cases than controls exposed to measured or calculated fields above 2 mG. The author concludes that the analysis supports an association, although the size of the effect is small to moderate, but also notes “limitations due to design, confounding, and other biases may suggest alternative interpretations” (Wartenberg, 2001b:S-100).

The results of this meta-analysis are not directly comparable to previous ones regarding fields of 3 or 4 mG because the analysis was not based on individual data. The comparison of grouped data used different exposure cut points for the analysis and different criteria for the comparison group. None of these three analyses (Ahlbom et al., 2000; Greenland et al., 2000; Wartenberg, 2001b) included the results of the latest UK analysis of 1331 child leukemia cases based on calculated fields, which found no association between EMF and childhood leukemia or other cancers, regardless of the exposure level.

2.2.2 Epidemiology Studies of Adults

Studies of adults with certain types of cancer, such as brain cancer, breast cancer, or leukemia, have reported associations with exposure to magnetic fields at residences, but results have not been consistent across studies. Contradictory results among studies argue against a conclusion that the association reflects a cause-and-effect relationship. In their assessments of risk, scientists give most weight to studies that include more people, obtain more detailed and individual exposure assessments, and/or include people who have higher exposures.

A study of 492 adult cases of brain cancer in California included measurements of magnetic fields taken in the home and at the front door, and considered the types of power-line wiring (Wrensch et al., 1999). The authors report no evidence of increased risk with higher exposures, no association with type of power line, and no link with levels measured at the front door.

A number of recent studies of breast cancer focused on electric blankets as a source of high exposure. Electric blankets are assumed to be one of the strongest sources of EMF exposure in the home. Three studies of electric-blanket use found no evidence that long-term use increased the risk of breast cancer. Women who developed breast cancer reported no difference in total use of electric blankets, use in recent years, or use many years in the past:

- Gammon et al. (1998) reported that, even for those who kept the blanket on most of the time, no increase in risk was found for those who had longer duration of use (measured in months).

- A study of 608 breast cancer cases found no evidence of increased use of electric blankets or other home appliances in cases compared to controls, and no indication of increasing risk with a longer time of use (Zheng et al., 2000).

- In a cohort of over 120,000 female nurses, data were obtained on known risk factors for breast cancer as well as electric-blanket use (Laden et al., 2000). For a large subset of this group, the questions about exposure were asked before the disease occurred, a step taken to eliminate bias in recalling exposure. No associations with electric blanket use were found.

Erren (2001) reported the results of a meta-analysis of the studies of breast cancer, in which the results of 24 different studies in women were statistically aggregated. When the results of all 24 studies, including studies of workplace exposures, were pooled, the estimate indicated an association between EMF and a small excess breast cancer risk. The pooled results for exposure to EMF in the vicinity of electrical facilities did not show an association with breast cancer, nor did the results for exposure to EMF from appliance use. However, the meta-analysis also showed a lack of consistency among the results of the individual studies, a broad variation in the designs, and a wide range of methods used to assess exposure. No adjustments were made to the data to give increased weight to studies based on more comprehensive exposure assessments. The author also noted that the weak statistical association might be an artifact (a result of chance or unforeseen error) rather than an indication of a cause-and-effect relationship (Erren, 2001).

2.2.3 Laboratory Studies of EMF

Laboratory studies complement epidemiologic studies of people because the effects of heredity, diet, and other health-related exposures of animals can be better controlled or eliminated. The assessment of EMF and health, as for any other exposure, includes chronic, long-term studies in animals (*in vivo* studies) and studies of changes in genes or other cellular processes observed in isolated cells and tissues in the laboratory (*in vitro*).

Although the results of the RAPID Program were described in some detail in the NIEHS reports (NIEHS, 1998), many of the studies had not been published in the peer-reviewed literature. The RAPID research program included studies of four biological effects, each of which had previously been observed in only one laboratory. These effects are as follows: effects on gene expression, increased intracellular calcium in a human cell line, proliferation of cell colonies on agar, and increased activity of the enzyme ornithine decarboylase (ODC). Some scientists have suggested that these biological responses are signs of possible adverse health effects of EMF. It is standard scientific procedure to attempt to replicate results in other laboratories, because artifacts and investigator error can occur in scientific investigations. Replications, often using more experiments or more rigorous protocols, help to ensure objectivity and validity. Attempts at replication can substantiate and strengthen an observation, or they may discover the underlying reason for the observed response.

Studies in the RAPID program reported no consistent biological effects of EMF exposure on gene expression, intracellular calcium concentration, growth of cell colonies on agar, or ODC activity (Boorman et al., 2000b). For example, Balcer-Kubiczek et al. (2000) and Loberg et al. (2000) studied the expression of hundreds of cancer-related genes in human mammary or leukemia cell lines. They found no increase in gene expression with increased intensity of magnetic fields. To test the experimental procedure, they used X-rays and treatments known to affect the genes. These are known as positive controls and, as expected, caused gene expression in exposed cells.

Scientists have concluded that the combined animal bioassay results provide no evidence that magnetic fields cause, enhance, or promote the development of leukemia and lymphoma, or mammary cancer (e.g., Boorman et al., 1999; McCormick et al., 1999; Boorman et al., 2000 a, b; Anderson et al., 2001).

2.2.4 Summary Regarding Cancer

Epidemiology studies do not support the idea that EMF from power lines increase the risk of cancers in adults. The latest epidemiologic studies of childhood cancer, considered in the context of the other data, provide no persuasive evidence that leukemia in children is causally associated with magnetic fields measured at the home, calculated magnetic fields based on distance and current loading, or wire codes. Recent meta-analyses reported no association between childhood cancer and magnetic fields below 2 or 3 mG. Although some association was reported for fields above this level, fields at most residences are likely to be below 3 or 4 mG. The authors of each of these analyses list several biases and problems that render the data inconclusive and prevent resolution of the inconsistencies in the epidemiologic data. For this reason, laboratory studies can provide important complementary information. Large, well-conducted animal studies and studies of initiation and promotion, provide no basis to conclude that EMF increases leukemia, lymphoma, breast, brain, or any other type of cancer.

2.3 Research Related to Reproduction

Previous epidemiologic studies reported no association with birth weight or fetal growth retardation after exposure to sources of relatively strong magnetic fields, such as electric blankets, or sources of typically weaker magnetic fields such as power lines (Bracken et al., 1995; Belanger et al., 1998).

A recent epidemiology study examined miscarriages[2] in relation to exposures to magnetic fields from electric bed-heating (electric blankets, heated waterbeds and mattress pads), which result in higher exposures than residential fields in general (Lee et al., 2000). The researchers assessed exposure prior to the birth (a prospective study) and included information to control for potential confounding factors (other exposures and conditions that affect the risk of miscarriage). This study had a large number of cases and high participation rates. Miscarriage rates were lower among users of electric bed-heating.

Studies of laboratory animals exposed to pure 60-Hz fields have shown no increase in birth defects, no multigenerational effects, and no changes that would indicate an increase in miscarriage or loss of fertility (e.g., Ryan et al., 1999; Ryan et al., 2000). Exposed and unexposed litters were no different in the amount of fetal loss and the number and type of birth defects, indicating no reproductive effect of EMF.

In summary, the recent evidence from epidemiology and laboratory studies provides no indication that exposure to power-frequency EMF has an adverse effect on reproduction, pregnancy, or growth and development of the embryo. The results of these recent studies are consistent with the conclusions of the NIEHS.

2.4 Power-line Electric Fields and Airborne Particles and Ions

Researchers from a university in England have suggested that the alternating-current (ac) electric fields from power lines might affect health indirectly, by interacting with the electrical charges on certain airborne particles in the air. They hypothesize that more particles would be deposited on the skin by a strong electric field, or in the lung by charges on particles (Henshaw et al., 1996; Fews et al., 1999a, b).

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[2] The medical term for miscarriage is spontaneous abortion.

If this hypothesis were correct, and interaction did occur (i.e., the airborne particles were charged to increase deposition on skin and in lungs to a sufficient degree), then the researchers further hypothesize that human exposure to various airborne particles and disease might increase. These hypotheses remain highly speculative; scientists have found their assumptions unconvincing, and recognize data gaps in the steps of the hypotheses. Nevertheless, questions about effects of these charged particles have been raised in the media.

In their laboratory, Henshaw and colleagues have developed models to test the physical assumptions that are the first step of their hypotheses: that electric fields can change the behavior of particulates in the air. For example, they measured the deposition of radon daughter[3] particles on metal plates, in the presence of electric fields at intensities found under or near power lines. They also reported increased deposition at similar electric field strengths outdoors near high voltage transmission lines. Under these conditions, deposition of products on surfaces was slightly increased, an occurrence that implies that the deposition might also occur on other surfaces, such as the skin. However, Henshaw and colleagues have not tested the most speculative parts of their hypothesis: that such changes in the deposition rate of particles would lead to an important increase in human exposure, and also that the increased skin exposure would be sufficient to affect human health, in this case to cause an increase in skin cancer. Given (a) the small change anticipated, (b) the ability of wind to disperse particles, and (c) the limited amount of time that people spend outdoors directly under high-voltage power lines, the assumption of health effects is unsupported (Swanson and Jeffers, 2000).

Henshaw et al. also hypothesize that ac electric fields at the surface of power line conductors lead to increased charges on particles, and thereby increase the likelihood that inhaled particles, including radon daughters, would be deposited on surfaces inside the lung or airways, even at considerable distances from the line. Air contains particles of various sizes, including aerosols[4] from emissions from cars and trucks and manufacturing, as well as natural sources such as radon from soil, rock, and building materials. If, as hypothesized, charges on the aerosol particles were increased, and if this change were to increase deposition in the lungs when inhaled over long periods of time, in theory these events could lead to increases in respiratory disease, and possibly other diseases.

The physical basis for aspects of these hypotheses is reasonable. However, the other steps of the hypothesis are highly speculative, and the idea that power lines could substantially affect human exposure to airborne particles or lead to adverse health effects is unwarranted (Swanson and Jeffers, 2000).

The National Radiological Protection Board (NRPB) of Great Britain considered the hypotheses and data published by Fews et al. regarding aerosol deposition increased by electric fields (1999a) and exposure to corona ions from power lines (1999b). The NRPB report (2001) concluded:

> The physical principles for enhanced aerosol deposition in large electric fields are well understood. However, it has not been demonstrated that any such enhanced deposition will increase human exposure in a way that will result in adverse health effects to the general public (NRPB, 2001: 23).

2.5 Recent Reviews by Scientific Advisory Groups

Reviews of the scientific research regarding EMF and health by the Health Council of the Netherlands (HCN) were published in 2000 and updated in May 2001. The Institute of Electrical Engineers of Great

[3] Radon daughters refers to the radioactive decay products of radon (^{222}Rn).
[4] An aerosol is a relatively stable suspension of solid particles or liquid droplets in a gaseous medium.

Britain (IEE) published a review in 2000. The NRPB Advisory Group on Non-Ionising Radiation (AGNIR) published the most recent review in 2001. That review includes research published in 2000, and includes the most comprehensive discussion of the individual research studies. The International Agency for Research on Cancer (IARC) evaluated health effects of EMF and released a statement regarding their findings in June 2001.

2.5.1 National Radiological Protection Board of Great Britain (NRPB) Advisory Group on Non-Ionising Radiation

The conclusions from the report prepared by the NRPB's Advisory Group on Non-Ionising Radiation (AGNIR) on ELF-EMF and the risk of cancer are consistent with previous reviews. Members from universities, medical schools, and cancer research institutes reviewed the reports of experimental and epidemiological studies, including reports in the literature in 2000. Their general conclusions are as follows:

> Laboratory experiments have provided no good evidence that extremely low frequency electromagnetic fields are capable of producing cancer, nor do human epidemiological studies suggest that they cause cancer in general. There is, however, some epidemiological evidence that prolonged exposure to higher levels of power frequency magnetic fields is associated with a small risk of leukaemia in children. In practice, such levels of exposure are seldom encountered by the general public in the UK [or in the U.S.] (NRPB, 2001: 164).

The group further recognizes that the scientific evidence suggesting that exposure to power-frequency electromagnetic fields poses an increased risk of cancer is very weak. Virtually all of the cellular, animal and human laboratory evidence provides no support for an increased risk of cancer incidence following such exposure to power frequencies, although sporadic positive findings have been reported. In addition, the epidemiological evidence is, at best, weak.

These conclusions of the Advisory Group are consistent with previous reviews by the NIEHS (1999) and the Health Council of the Netherlands (HCN, 2000). The NRPB response to the Advisory Group report states that "the review of experimental studies by [the Advisory Group] AGNIR gives no clear support for a causal relationship between exposure to ELF-EMFs and cancer" (NRPB, 2001: 1).

2.5.2 Health Council of the Netherlands (HCN)

The Health Council of the Netherlands has prepared updates of its 1992 Advisory Report on exposure to electromagnetic fields (0 Hz to 10 MHz) (HCN, 2000; 2001). Members of the Expert Committee who prepared the report include specialists in physics, biology, and epidemiology. The Expert Committee based its analysis on the review and summaries of the studies provided in the NIEHS (1998) and concurred with the views of the director of the NIEHS (1999). For the update, the Committee evaluated a number of publications that appeared after these reports, e.g., McBride et al., (1999) and Green et al. (1999a), and wrote:

> The committee thinks that the quality of the relevant epidemiological research has improved considerably since the publication of the advisory report in 1992. Even so, this research has not resulted in unequivocal, scientifically reliable conclusions (HCN, 2000: 15).

The Council emphasizes that the associations with EMF reported in epidemiologic studies are strictly statistical and do not demonstrate a cause-and-effect relationship. In their view, experimental research does not demonstrate a causal link or a mechanism to explain EMF as a cause of disease in humans. They concluded that there is no reason to recommend measures to limit residence near overhead power lines (HCN, 2000).

The 2001 update (HCN, 2001) includes three major studies (described above) published in 2000 and 2001 (Ahlbom et al., 2000; Greenland et al., 2000; Wartenberg 2001b). The Council concludes:

> Because the association is only weak and without a reasonable biological explanation, it is not unlikely that [an association between ELF exposure and childhood leukemia] could also be explained by chance . . . . The committee therefore sees no reason to modify its earlier conclusion that the association is not likely to be indicative of a causal relationship (HCN, 2001: 40).

2.5.3 Institution of Electrical Engineers (IEE) of Great Britain

One of the recent reviews was that of the Institution of Electrical Engineers (IEE) of Great Britain (IEE, 2000). In 1992, the IEE set up a Working Party whose eight members, with broad expertise in the health sciences, review the relevant scientific literature and prepare reports of their views. Their conclusion is based on recent major epidemiologic studies and the scientific literature built up over the past 20 years. In May 2000, the Working Party concluded " . . . that there is still not convincing scientific evidence showing harmful effects of low level electromagnetic fields on humans" (IEE, 2000:1).

2.5.4 International Agency for Research on Cancer (IARC)

The International Agency for Research on Cancer sponsored a review of EMF research by a Working Group of scientific experts from 10 countries. This multidisciplinary group reviewed health effects of ELF-EMF. Although their monograph is still in preparation, IARC has released a summary of the Group's conclusions. The Working Group concluded that the epidemiologic studies do not provide support for an association between childhood leukemia and residential magnetic fields at intensities less than 4 mG. IARC reviewers also evaluated the animal data and concluded that it was "inadequate" to support a risk for cancer. Their summary states that the EMF data does not merit the category "carcinogenic to humans" or the category "probably carcinogenic to humans," nor did they find that "the agent is probably not carcinogenic to humans" (IARC, 2001).

2.6 Summary

The results of the latest epidemiologic studies of childhood cancer do not provide convincing evidence to support the hypothesis that exposure to magnetic fields or power lines near the home are a cause of leukemia in children. The larger, more reliable, residential studies do not support the idea that fields in the residence contribute to the risk of cancer in adults. Although epidemiology studies provide evidence most relevant to humans, the results may include uncertainties because they are observational rather than experimental. For this reason, laboratory studies can provide important complementary information. The larger and more thorough animal studies that exposed animals for EMF for their entire lifespan show no increases in cancer or other adverse health effects, including reproduction outcomes, in exposed animals.

3.0 Ecological Research

Scientists have studied the effects of high-voltage transmission lines on many plant and animal species in the natural environment. In this section, the research on the effects of EMF on ecological systems to assess the likelihood of adverse impacts was briefly reviewed. In addition to the comprehensive review of research on this topic by wildlife biologists at BPA (Lee et al., 1996), a search of the published scientific literature for more recent studies published between 1995 and June 2001 was conducted.

3.1 Fauna

The habitat on the transmission-line right-of-way and surrounding area shields most wildlife from electric fields. Vegetation in the form of grasses, shrubs, and small trees largely shields small ground-dwelling species such as mice, rabbits, foxes, and snakes from electric fields. Species that live underground, such as moles, woodchucks, and worms, are further shielded from electric fields by the soil. Hence, large species such as deer and domestic livestock (e.g., sheep and cattle) have greater potential exposures to electric fields since they can stand taller than surrounding vegetation. However, the duration of exposure for deer and other large animals is likely to be limited to foraging bouts or the time it takes them to cross under the line. Furthermore, all species would be exposed to higher magnetic fields under a transmission line than elsewhere, as the vegetation and soil do not provide shielding from this aspect of the transmission-line electrical environment.

Field studies have been performed in which the behavior of large mammals in the vicinity of high-voltage transmission lines was monitored. No effects of electric or magnetic fields were evident in two studies from the northern United States on big game species, such as deer and elk, exposed to a 500-kilovolt (kV) transmission line (Goodwin 1975; Picton et al., 1985). In such studies, a possible confounding factor is audible noise. Audible noise associated with high-voltage power transmission lines (with voltages greater than 110-kV) is due to corona. Audible noise generated by transmission lines reaches its highest levels in inclement weather (rain or snow).

Much larger populations of animals that might spend time near a transmission line are livestock that graze under or near transmission lines. To provide a more sensitive and reliable test for adverse effects than informal observation, scientists have studied animals continuously exposed to fields from the lines in relatively controlled conditions. For example, grazing animals such as cows and sheep have been exposed to high-voltage transmission lines and their reproductive performance examined (Lee et al., 1996). No adverse effects were found among cattle exposed over one or more successive breedings to a 500-kV direct-current overhead transmission line (Angell et al., 1990). Compared to unexposed animals in a similar environment, the exposure to 50-Hz fields did not affect reproductive functions or pregnancy of cows (Algers and Hennichs, 1985; Algers and Hultgren, 1987).

A group of investigators from Oregon State University, Portland State University, and other academic centers evaluated the effects of long-term exposure to EMF from a 500-kV transmission line operated by BPA on various cellular aspects of immune response, including the production of proteins by leukocytes (IL-1 and IL-2) of sheep. In previous unpublished reports, the researchers found differences in IL-1 activity between exposed and control groups. However, in their most recent replication, the authors found no evidence of differences in these measures of immune function. The sheep were exposed to 27 months of continuous exposure to EMF, a period of exposure much greater than the short, intermittent exposures that sheep would incur grazing under transmission lines. Mean exposures of EMF were 3.5-3.8 μT (35-38 mG) and 5.2-5.8 kV/m, respectively (Hefeneider et al., 2001).

Scientists from the Illinois Institute of Technology (IIT) monitored the possible effects of electric and magnetic fields on fauna and flora in Michigan and Wisconsin from 1969 – 1997 to evaluate the effects of an above-ground, military-communications antenna operating at 76 Hz. The antenna produces EMF similar in physical characteristics to those produced by high-voltage transmission lines, but of much lower intensity. This study, which included embryonic development, fertility, postnatal growth, maturation, aerobic metabolism, and homing behavior, showed no adverse impacts of ELF electric and magnetic fields on the animals (NRC, 1997).

The hormone melatonin, secreted at night by the pineal gland, plays a role in animals that are seasonal breeders. Studies in laboratory mice and rats have suggested that exposure to electric and/or magnetic fields might affect levels of the hormone melatonin, but results have not been consistent (Wilson et al., 1981; Holmberg, 1995; Kroeker et al., 1996; Vollrath et al., 1997; Huuskonen et al., 2001). However, when researchers examined sheep and cattle exposed to EMF from transmission lines exceeding 500-kV, they found no effect on the levels of the hormone melatonin in blood, weight gain, onset of puberty, or behavior in sheep and cattle (Stormshak et al., 1992; Lee et al., 1993; Lee et al., 1995; Thompson et al., 1995; Burchard et al., 1998).

Another part of the IIT study examined the effect of the antenna system fields on the growth, development, and homing behavior of birds. Studies of embryonic development (Beaver et al., 1993), fertility, postnatal growth, maturation, aerobic metabolism, and homing behavior showed no adverse impacts of ELF electric and magnetic fields on the animals (NRC, 1997). Fernie and colleagues studied the effects of continuous EMF exposure of raptors to an electric field of 10 kV/m in a controlled, laboratory setting. The exposure was designed to mimic exposure to a 765-kV transmission line. Continuous EMF exposure was found to reduce hatching success and increase egg size, fledging success, and embryonic development (Fernie et al., 2000). In a study of the effects on body mass and food intake of reproducing falcons, the authors found that EMF lengthened the photoperiod as a result of altered melatonin levels in the male species, yet concluded that "EMF effects on adult birds may only occur after continuous, extended exposure," which is not likely to occur from resting on power lines (Fernie and Bird, 1999:620).

Several avian species are reported to use the earth's magnetic field as one of the cues for navigation. It has been proposed that deposits of magnetite in specialized cells in the head are the mechanism by which the birds can detect variations in the inclination and intensity of a direct-current (dc) magnetic field (Kirschvink and Gould, 1981; Walcott et al., 1988). In early studies of transmission lines, it was reported that the migratory patterns of birds appeared to be altered near transmission lines (Southern, 1975; Larkin and Sutherland, 1977). However, these studies were of crude design, and Lee et al. (1996) concluded that, "During migration, birds must routinely fly over probably hundreds (or thousands) of electrical transmission and distribution lines. We are not aware of any evidence to suggest that such lines are disrupting migratory flights" (Lee et al., 1996:4-59). No further studies on this topic were identified in the literature.

Bees, like birds, are able to detect the earth's dc magnetic fields. They are known to use magnetite particles, which are contained in an abdominal organ, as a compass (Kirschvink and Gould, 1981). In the laboratory, they are able to discriminate between a localized magnetic anomaly and a uniform background dc magnetic field (Walker et al., 1982; Kirschvink et al., 1992).

Greenberg et al. (1981) studied honeybee colonies placed near 765-kV transmission lines. They found that hives exposed to electric fields of 7 kV/m had decreased hive weight, abnormal amounts of propolis (a resinous material) at hive entrances, increased mortality and irritability, loss of the queen in some hives, and a decrease in the hive's overall survival compared to hives that were not exposed. Exposure to electric fields of 7-12 kV/m may induce a current or heat the interior of the hive; however, placing the hive farther from the line, shielding the hive, or using hives without metallic parts eliminates this problem. ITT studied the effects of EMF on bees exposed to the 76-Hz antenna system at lower intensities and concluded that these behavioral effects of "ELF-EMF impacts are absent or at most minimal" (NRC, 1997:102).

Reptiles and amphibians contribute to the overall functioning of the forest ecosystems. However, little research has been performed on the effects of EMF on reptiles and amphibians in their natural habitat.

3.2 Flora

Numerous studies have been carried out to assess the effect of exposure of plants to transmission-line electric and magnetic fields. These studies have involved both forest species and agriculture crops. Researchers have found no adverse effects on plant responses, including seed germination, seedling emergence, seedling growth, leaf area per plant, flowering, seed production, germination of the seeds, longevity, and biomass production (Lee et al., 1996).

The only confirmed adverse effect of transmission lines on plants was reported for transmission lines with voltages above 1200 kV. For example, Douglas Fir trees planted within 15 m of the conductors were shorter than trees planted away from the line. Shorter trees are believed to result from corona-induced damage to the branch tips. Trees between 15 and 30 m away from the line suffered needle burns, but those 30 m and beyond were not affected (Rogers et al., 1984). These effects would not occur at the lower field intensities expected beyond the right-of-way of the proposed 500-kV transmission line.

3.3 Summary

The habitat on the transmission-line rights-of-way and surrounding areas shields smaller animals from electric fields produced by high-voltage transmission lines; thus, vegetation easily shields small animals from electric fields. The greatest potential for larger animals to be exposed to EMF occurs when they are passing beneath the lines. Studies of animal reproductive performance, behavior, melatonin production, immune function, and navigation have found minimal or no effects of EMF. Past studies have found little effect of EMF on plants; no recent studies of plants growing near transmission lines have been performed. In summary, the literature published to date has shown little evidence of adverse effects of EMF from high-voltage transmission lines on wildlife and plants. At the field intensities associated with the proposed 500-kV transmission line, no adverse effects on wildlife or plants are expected.

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<u>MCNARY – JOHN DAY 500-kV TRANSMISSION-LINE PROJECT</u>

ELECTRICAL EFFECTS

January 2002

Prepared by

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for

Bonneville Power Administration

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ELECTRICAL EFFECTS FROM THE PROPOSED MCNARY — JOHN DAY TRANSMISSION-LINE PROJECT

1.0 Introduction

The Bonneville Power Administration (BPA) is proposing to build a 87-mile (mi.) (140- kilometer [km]) 500-kilovolt (kV) transmission line from the existing BPA McNary Substation near the McNary Dam on the Columbia River, to the existing BPA John Day Substation near the John Day Dam on the Columbia River. The proposed line is designated the McNary – John Day 500-kV line. The proposed line would be built on new and existing right-of-way. Although both substations are located on the south (Oregon) side of the river, most of the proposed line route is on the north (Washington) side of the river. For most of its length the proposed line would parallel existing 230- and 345-kV lines. For some portions of the route, the proposed line would also parallel existing 500-kV lines and in one section there would be no parallel lines within about 600 feet of the line. The parallel line configurations and their lengths are given in Table 1. The purpose of this report is to describe and quantify the electrical effects of the proposed McNary – John Day 500-kV transmission line. These effects include the following:

- the levels of 60-hertz (Hz; cycles per second) electric and magnetic fields (EMF) at 3.28 feet (ft.) or 1 meter (m) above the ground,
- the effects associated with those fields,
- the levels of audible noise produced by the line, and
- electromagnetic interference associated with the line.

Electrical effects occur near all transmission lines, including those 500-kV lines already present in the area of the proposed route for the McNary – John Day line. Therefore, the levels of these quantities for the proposed line are computed and compared with those from the existing lines in Oregon, Washington, and elsewhere.

The voltage on the conductors of transmission lines generates an *electric field* in the space between the conductors and the ground. The electric field is calculated or measured in units of volts-per-meter (V/m) or kilovolts-per-meter (kV/m) at a height of 3.28 ft. (1 m) above the ground. The current flowing in the conductors of the transmission line generates a *magnetic field* in the air and earth near the transmission line; current is expressed in units of amperes (A). The magnetic field is expressed in milligauss (mG), and is also usually measured or calculated at a height of 3.28 ft. (1 m) above the ground. The electric field at the surface of the conductors causes the phenomenon of *corona*. Corona is the electrical breakdown or ionization of air in very strong electric fields, and is the source of audible noise, electromagnetic radiation, and visible light.

To quantify EMF levels along the route, the electric and magnetic fields from the proposed and existing lines were calculated using the BPA Corona and Field Effects Program (USDOE, undated). In this program, the calculation of 60-Hz fields uses standard superposition techniques for vector fields from several line sources: in this case, the line sources are transmission-line conductors. (Vector fields have both magnitude and direction: these must be taken into account when combining fields from different sources.) Important input parameters to the computer program are voltage, current, and geometric configuration of the line. The transmission-line conductors are assumed to be straight, parallel to each other, and located above and parallel to an infinite flat ground plane. Although such conditions do not occur under real lines because of conductor sag and variable terrain, the validity and limitations of calculations using these assumptions have been well verified by comparisons with measurements. This approach was used to estimate fields for the proposed McNary – John Day line, where minimum clearances were assumed to provide worst-case (highest) estimates for the fields.

Electric fields are calculated using an imaging method. Fields from the conductors and their images in the ground plane are superimposed with the proper magnitude and phase to produce the total field at a selected location.

The total magnetic field is calculated from the vector summation of the fields from currents in all the transmission-line conductors. Balanced currents are assumed for each three-phase circuit; the contribution of induced image currents in the conductive earth is not included.

Electric and magnetic fields for the proposed line were calculated at the standard height (3.28 ft. or 1 m) above the ground (IEEE, 1987). Calculations were performed out to 300 ft. (91 m) from the centerline of the existing corridor. The validity and limitations of such calculations have been well verified by measurements. Because maximum voltage, maximum current, and minimum conductor height above-ground are used, ***the calculated values given here represent worst-case conditions:*** i.e., the calculated fields are higher than they would be in practice. Such worst-case conditions would seldom occur.

The corona performance of the proposed line was also predicted using the BPA Corona and Field Effects Program (USDOE, undated). Corona performance is calculated using empirical equations that have been developed over several years from the results of measurements on numerous high-voltage lines (Chartier and Stearns, 1981; Chartier, 1983). The validity of this approach for corona-generated audible noise has been demonstrated through comparisons with measurements on other lines all over the United States (IEEE Committee Report, 1982). The accuracy of this method for predicting corona-generated radio and television interference from transmission lines has also been established (Olsen et al., 1992). Important input parameters to the computer program are voltage, current, conductor size, and geometric configuration of the line.

Corona is a highly variable phenomenon that depends on conditions along a length of line. Predictions of the levels of corona effects are reported in statistical terms to account for this variability. Calculations of audible noise and electromagnetic interference levels were made under conditions of an estimated average operating voltage (98 percent of maximum voltage) and with the average line height over a span: 540 kV and about 45 ft. (13.7 m) clearance for the proposed 500-kV line. Levels of audible noise, radio interference, and television interference are predicted for both fair and foul weather; however, corona is basically a foul-weather phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Along the route of the proposed McNary – John Day transmission line, such conditions are expected to occur about 1% of the time during a year, based on hourly precipitation records recorded at Arlington, Oregon during 1997 – 2000. Corona activity also increases with altitude. For purposes of evaluating corona effects from the proposed line, an altitude of 600 ft. (183 m) was assumed.

2.0 Physical Description

2.1 Proposed Line

The proposed 500-kV transmission line would be a three-phase, single-circuit line with the phases arranged in a delta (triangular) configuration. The maximum phase-to-phase voltage would be 550 kV; the average voltage would be 540 kV. The maximum electrical current on the line would be 1758 A per phase, based on the BPA projected normal system annual peak load with 2004 as the base year. The load factor for this load would be about 0.50 (average load = peak load x load factor). BPA provided the physical and operating characteristics of the proposed and existing lines.

The electrical characteristics and physical dimensions for the configuration of the proposed line are shown in Figure 1, and summarized in Table 2. Each phase of the proposed 500-kV line would have three 1.3-inch (in.) (3.30-centimeter [cm]) diameter conductors (ACSR: steel-reinforced aluminum conductor) arranged in an inverted triangle bundle configuration, with 17-in. (43.3-cm) spacing between conductors. Voltage and current waves are displaced by 120° in time (one-third of a cycle) on each electrical phase. The horizontal phase spacing between the lower conductor positions would be 48 ft. (14.6 m). The vertical spacing between the conductor positions would be 34.5 ft. (10.5 m). (The spacing between conductor locations would vary slightly where special towers are used, such as at angle points along the line.)

Minimum conductor-to-ground clearance would be 35 ft. (10.7 m) at a conductor temperature of 122°F (50°C), which represents maximum operating conditions and high ambient air temperatures; clearances above ground would be greater under normal operating temperatures. The average clearance above ground along a span would be approximately 45 ft. (13.7 m); this value was used for corona calculations. At road crossings, the ground clearance would be at least 54 ft. (16.5 m). The 35-ft. (10.7-m) minimum clearance provided by BPA is greater than the minimum distance of the conductors above ground required to meet the National Electrical Safety Code (NESC) (IEEE, 2002). The final design of the proposed line could entail larger clearances. The right-of-way width for the proposed line would vary depending on location and the presence of parallel lines. The distance from the centerline of the proposed line to the edge of the right-way would vary from 72.5 ft. (22 m) to 187.5 ft. (57 m).

2.2 Existing Lines

Six possible corridor configurations were identified for analyzing electrical effects along the route from McNary Substation to John Day Substation (Table 1). These configurations are:

1) the proposed line parallel to and north of the existing McNary – Horse Heaven – Harvalum 230-kV and McNary – Ross No. 1 345-kV lines;

2) the proposed line parallel to and north of the existing 230-kV and 345-kV lines and the existing Ashe – Marion No. 1/Ashe – Slatt No. 1 double circuit 500-kV line;

3) the proposed line with no parallel lines within 600 feet;

4) the proposed line parallel to and 125 feet south of the existing 230-kV and 345-kV lines and the existing Hanford – John Day 500-kV line;

4A) the proposed line located on the existing Hanford – John Day 500-kV towers and parallel to and north of the existing McNary – Horse Heaven – Harvalum 230-kV and McNary – Ross No. 1 345-kV lines (The existing Hanford – John Day 500-kV line would be relocated on new towers north of the proposed line.); and

4B) the proposed line parallel to and 275 feet south of the existing 230-kV and 345-kV lines and the existing Hanford – John Day 500-kV line.

Configurations 4, 4A, and 4B are possible alternatives in the short section of the route where the proposed line parallels the existing Hanford – John Day 500-kV line; their presence and respective lengths would depend on the final engineering design for the line.

The physical and electrical characteristics of the corridor configurations that were analyzed are given in Table 2; cross-sections of the corridors are shown in Figure 1. Short sections of the proposed line entering the substations were not analyzed.

Changes in the electrical phasing of the existing lines in Configuration 1 occur and would affect field levels slightly. The four phasing schemes produce similar electric and magnetic fields and only the maximum results for field calculations are included here. In portions of Configuration 1, it may be necessary to increase the ground clearance to 37 feet (11.3 m) to ensure that the BPA criterion of 9 kV/m for peak electric field is met. BPA would select the means of achieving the 9-kV/m field criterion during the engineering design of the line. Corona effects from all phasing schemes of Configuration 1 were essentially the same. The maximum levels for fields and corona effects computed for the different phasing schemes are reported here.

3.0 Electric Field

3.1 Basic Concepts

An electric field is said to exist in a region of space if an electrical charge, at rest in that space, experiences a force of electrical origin (i.e., electric fields cause free charges to move). Electric field is a vector quantity: that is, it has both magnitude and direction. The direction corresponds to the direction that a positive charge would move in the field. Sources of electric fields are unbalanced electrical charges (positive or negative) and time-varying magnetic fields. Transmission lines, distribution lines, house wiring, and appliances generate electric fields in their vicinity because of unbalanced electrical charge on energized conductors. The unbalanced charge is associated with the voltage on the energized system. On the power system in North America, the voltage and charge on the energized conductors are cyclic (plus to minus to plus) at a rate of 60 times per second. This changing voltage results in electric fields near sources that are also time-varying at a frequency of 60 hertz (Hz; a frequency unit equivalent to cycles per second).

As noted earlier, electric fields are expressed in units of volts per meter (V/m) or kilovolts (thousands of volts) per meter (kV/m). Electric- and magnetic-field magnitudes in this report are expressed in root-mean-square (rms) units. For sinusoidal waves, the rms amplitude is given as the peak amplitude divided by the square root of two.

The spatial uniformity of an electric field depends on the source of the field and the distance from that source. On the ground, under a transmission line, the electric field is nearly constant in magnitude and direction over distances of several feet (1 meter). However, close to transmission- or distribution-line conductors, the field decreases rapidly with distance from the conductors. Similarly, near small sources such as appliances, the field is not uniform and falls off even more rapidly with distance from the device. If an energized conductor (source) is inside a grounded conducting enclosure, then the electric field outside the enclosure is zero, and the source is said to be shielded.

Electric fields interact with the charges in all matter, including living systems. When a conducting object, such as a vehicle or person, is located in a time-varying electric field near a transmission line, the external electric field exerts forces on the charges in the object, and electric fields and currents are induced in the object. If the object is grounded, then the total current induced in the body (the "short-circuit current") flows to earth. The distribution of the currents within, say, the human body, depends on the electrical conductivities of various parts of the body: for example, muscle and blood have higher conductivity than bone and would therefore experience higher currents.

At the boundary surface between air and the conducting object, the field both in the air and perpendicular to the conductor surface is much, much larger than the field in the conductor itself. For example, the average surface field on a human standing in a 10 kV/m field is 27 kV/m; the internal fields in the body are much smaller: approximately 0.008 V/m in the torso and 0.45 V/m in the ankles.

3.2 Transmission-line Electric Fields

The electric field created by a high-voltage transmission line extends from the energized conductors to other conducting objects such as the ground, towers, vegetation, buildings, vehicles, and people. The calculated strength of the electric field at a height of 3.28 ft. (1 m) above an unvegetated, flat earth is frequently used to describe the electric field under straight parallel transmission lines. The most important transmission-line parameters that determine the electric field at a 1-m height are conductor height above ground and line voltage.

Calculations of electric fields from transmission lines are performed with computer programs based on well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values under these conditions represent an ideal situation. When practical conditions approach this ideal model, measurements and calculations agree. Often, however, conditions are far from ideal because of variable terrain and vegetation. In these cases, fields are calculated for ideal conditions, with the lowest conductor clearances to provide upper bounds on the electric field under the transmission lines. With the use of more complex models or empirical results, it is also possible to account accurately for variations in conductor height, topography, and changes in line direction. Because the fields from different sources add vectorially, it is possible to compute the fields from several different lines if the electrical and geometrical properties of the lines are known. However, in general, electric fields near transmission lines with vegetation below are highly complex and cannot be calculated. Measured fields in such situations are highly variable.

For evaluation of EMF from transmission lines, the fields must be calculated for a specific line condition. The NESC states the condition for evaluating electric-field-induced short-circuit current for lines with voltage above 98 kV, line-to-ground, as follows: conductors are at a minimum clearance from ground corresponding to a conductor temperature of 120°F (49°C), and at a maximum voltage (IEEE, 2002). BPA has supplied the needed information for calculating electric and magnetic fields from the proposed transmission lines: the maximum operating voltage, the estimated peak current in 2004, and the minimum conductor clearances.

There are standard techniques for measuring transmission-line electric fields (IEEE, 1987). Provided that the conditions at a measurement site closely approximate those of the ideal situation assumed for calculations, measurements of electric fields agree well with the calculated values. If the ideal conditions are not approximated, the measured field can differ substantially from calculated values. Usually the actual electric field at ground level is reduced from the calculated values by various common objects that act as shields.

Maximum or peak field values occur over a small area at midspan, where conductors are closest to the ground. As the location of an electric-field profile approaches a tower, the conductor clearance increases, and the peak field decreases. A grounded tower will reduce the electric field considerably by shielding. For the parallel-line configurations considered here, minimum conductor clearances were assumed to occur along the same lateral profile for both lines. This condition will not necessarily occur in practice, because the towers for the parallel lines may be offset or located at different elevations. **The assumption of simultaneous minimum clearance results in peak (worst-case) fields that may be larger than what occurs in practice.**

For traditional transmission lines, such as the proposed line, where the right-of-way extends laterally well beyond the conductors, electric fields at the edge of the right-of-way are not as sensitive as the peak field to conductor height. Computed values at the edge of the right-of-way for any line height are fairly representative of what can be expected all along the transmission-line corridor. However, the presence of vegetation on and at the edge of the right-of-way will reduce actual electric-field levels below calculated values. The triangular arrangement of the conductor bundles for the proposed line reduces the electric and magnetic field levels below what they would be for a flat conductor arrangement.

3.3 Calculated Values of Electric Fields

Table 3 shows the calculated values of electric field at 3.28 ft. (1 m) above ground for the proposed McNary – John Day 500-kV transmission-line configurations. The peak value on the right-of-way and the value at the edge of the right-of-way are given for the six proposed configurations at minimum conductor clearances and at the estimated average clearance over a span. Figure 2 shows lateral profiles for the electric field for both existing and proposed configurations. Electric fields for the minimum and average line heights for the proposed line with no immediately adjacent parallel lines are shown in Figure 2c.

The calculated peak electric field expected on the right-of-way of the proposed line is 8.97 kV/m or less, depending on the configuration. For average clearance, the peak field would be 6.0 kV/m or less. As shown in Figure 2, the peak values would be present only at locations directly under the line, near mid-span, where the conductors are at the minimum clearance. The conditions of minimum conductor clearance at maximum current and maximum voltage occur very infrequently. The calculated peak levels are rarely reached under real-life conditions, because the actual line height is generally above the minimum value used in the computer model, because the actual voltage is below the maximum value used in the model, and because vegetation within and near the edge of the right-of-way tends to shield the field at ground level. The largest value expected at the edge of the right-of-way of the proposed line would be 2.8 kV/m. Maximum electric fields under the existing parallel 500-kV, 345-kV, and 230-kV lines are 8.9, 4.7 and 4.5 kV/m, respectively.

3.4 Environmental Electric Fields

The electric fields associated with the McNary – John Day 500-kV line can be compared with those found in other environments. Sources of 60-Hz electric (and magnetic) fields exist everywhere electricity is used; levels of these fields in the modern environment vary over a wide range. Electric-field levels associated with the use of electrical energy are orders of magnitude greater than naturally occurring 60-Hz fields of about 0.0001 V/m, which stem from atmospheric and extraterrestrial sources.

Electric fields in outdoor, publicly accessible places range from less than 1 V/m to 12 kV/m; the large fields exist close to high-voltage transmission lines of 500 kV or higher. In remote areas without electrical service, 60-Hz field levels can be much lower than 1 V/m. Electric fields in home and work environments generally are not spatially uniform like those of transmission lines; therefore, care must be taken when making comparisons between fields from different sources such as appliances and electric lines. In addition, fields from all sources can be strongly modified by the presence of conducting objects. However, it is helpful to know the levels of electric fields generated in domestic and office environments in order to compare commonly experienced field levels with those near transmission lines.

Numerous measurements of residential electric fields have been reported for various parts of the United States, Canada, and Europe. Although there have been no large studies of residential electric fields, sufficient data are available to indicate field levels and characteristics. Measurements of domestic 60-Hz electric fields indicate that levels are highly variable and source-dependent. Electric-field levels are not easily predicted because walls and other objects act as shields, because conducting objects perturb the field, and because homes contain numerous localized sources. Internal sources (wiring, fixtures, and appliances) seem to predominate in producing electric fields inside houses. Average measured electric fields in residences are generally in the range of 5 to 20 V/m. In a large occupational exposure monitoring project that included electric-field measurements at homes, average exposures for all groups away from work were generally less than 10 V/m (Bracken, 1990).

Electric fields from household appliances are localized and decrease rapidly with distance from the source. Local electric fields measured at 1 ft. (0.3 m) from small household appliances are typically in the range of 30 to 60 V/m. Stopps and Janischewskyj (1979) reported electric-field measurements near 20 different appliances; at a 1-ft. (0.3-m) distance, fields ranged from 1 to 150 V/m, with a mean of 33 V/m. In another survey, reported by Deno and Zaffanella (1982), field measurements at a 1-ft. (0.3-m) distance from common domestic and workshop sources were found to range from 3 to 70 V/m. The localized fields from appliances are not uniform, and care should be taken in comparing them with transmission-line fields.

Electric blankets can generate higher localized electric fields. Sheppard and Eisenbud (1977) reported fields of 250 V/m at a distance of approximately 1 ft. (0.3 m). Florig et al. (1987) carried out extensive empirical and theoretical analysis of electric-field exposure from electric blankets and presented results in terms of uniform equivalent fields such as those near transmission lines. Depending on what parameter was chosen to represent intensity of exposure and the grounding status of the subject, the equivalent vertical 60-Hz electric-field exposure ranged from 20 to over 3500 V/m. The largest equivalent field corresponds to the measured field on the chest with the blanket-user grounded. The average field on the chest of an ungrounded blanket-user yields an equivalent vertical field of 960 V/m. As manufacturers have become aware of the controversy surrounding EMF exposures, electric blankets have been redesigned to reduce *magnetic* fields. However, electric fields from these “low field” blankets are still comparable with those from older designs (Bassen et al., 1991).

Generally, people in occupations not directly related to high-voltage equipment are exposed to electric fields comparable with those of residential exposures. For example, the average electric field measured in 14 commercial and retail locations in rural Wisconsin and Michigan was 4.8 V/m (ITT Research Institute, 1984). Median electric field was about 3.4 V/m. These values are about one-third the values in residences reported in the same study. Power-frequency electric fields near video display terminals

(VTDs) are about 10 V/m, similar to those of other appliances (Harvey, 1983). Electric-field levels in public buildings such as shops, offices, and malls appear to be comparable with levels in residences.

In a survey of 1,882 volunteers from utilities, electric-field exposures were measured for 2,082 work days and 657 non-work days (Bracken, 1990). Electric-field exposures for occupations other than those directly related to high-voltage equipment were equivalent to those for non-work exposure.

Thus, except for the relatively few occupations where high-voltage sources are prevalent, electric fields encountered in the workplace are probably similar to those of residential exposures. Even in electric-utility occupations where high field sources are present, exposures to high fields are limited on average to minutes per day.

Electric fields found in publicly accessible areas near high-voltage transmission lines can typically range up to 3 kV/m for 230-kV lines, to 10 kV/m for 500-kV lines, and to 12 kV/m for 765-kV lines. Although these peak levels are considerably higher than the levels found in other public areas, they are present only in limited areas on rights-of-way.

The calculated electric fields for the proposed McNary – John Day 500-kV transmission line are consistent with the levels reported for other 500-kV transmission lines in Oregon, Washington, and elsewhere. The calculated electric fields on the right-of-way of the proposed transmission line would be much higher than levels normally encountered in residences and offices.

4.0 Magnetic Field

4.1 Basic Concepts

Magnetic fields can be characterized by the force they exert on a moving charge or on an electrical current. As with the electric field, the magnetic field is a vector quantity characterized by both magnitude and direction. Electrical currents generate magnetic fields. In the case of transmission lines, distribution lines, house wiring, and appliances, the 60-Hz electric current flowing in the conductors generates a time-varying, 60-Hz magnetic field in the vicinity of these sources. The strength of a magnetic field is measured in terms of magnetic lines of force per unit area, or magnetic flux density. The term “magnetic field,” as used here, is synonymous with magnetic flux density and is expressed in units of Gauss (G) or milligauss (mG).

The uniformity of a magnetic field depends on the nature and proximity of the source, just as the uniformity of an electric field does. Transmission-line-generated magnetic fields are quite uniform over horizontal and vertical distances of several feet near the ground. However, for small sources such as appliances, the magnetic field decreases rapidly over distances comparable with the size of the device.

The interaction of a time-varying magnetic field with conducting objects results in induced electric field and currents in the object. A changing magnetic field through an area generates a voltage around any conducting loop enclosing the area (Faraday's law). This is the physical basis for the operation of an electrical transformer. For a time-varying sinusoidal magnetic field, the magnitude of the induced voltage around the loop is proportional to the area of the loop, the frequency of the field, and the magnitude of the field. The induced voltage around the loop results in an induced electric field and current flow in the loop material. The induced current that flows in the loop depends on the conductivity of the loop.

4.2 Transmission-line Magnetic Fields

The magnetic field generated by currents on transmission-line conductors extends from the conductors through the air and into the ground. The magnitude of the field at a height of 3.28 ft. (1 m) is frequently used to describe the magnetic field under transmission lines. Because the magnetic field is not affected by non-ferrous materials, the field is not influenced by normal objects on the ground under the line. The direction of the maximum field varies with location. (The electric field, by contrast, is essentially vertical near the ground.) The most important transmission-line parameters that determine the magnetic field at 3.28 ft. (1 m) height are conductor height above ground and magnitude of the currents flowing in the conductors. As distance from the transmission-line conductors increases, the magnetic field decreases.

Calculations of magnetic fields from transmission lines are performed using well-known physical principles (cf., Deno and Zaffanella, 1982). The calculated values usually represent the ideal straight parallel-conductor configuration. For simplicity, a flat earth is usually assumed. Balanced currents (currents of the same magnitude for each phase) are also assumed. This is usually valid for transmission lines, where loads on all three phases are maintained in balance during operation. Induced image currents in the earth are usually ignored for calculations of magnetic field under or near the right-of-way. The resulting error is negligible. Only at distances greater than 300 ft. (91 m) from a line do such contributions become significant (Deno and Zaffanella, 1982). The clearance for magnetic-field calculations for the proposed line was the same as that used for electric-field evaluations.

Standard techniques for measuring magnetic fields near transmission lines are described in ANSI IEEE Standard No. 644-1987 (IEEE, 1987). Measured magnetic fields agree well with calculated values, provided the currents and line heights that go into the calculation correspond to the actual values for the line. To realize such agreement, it is necessary to get accurate current readings during field measurements (because currents on transmission lines can vary considerably over short periods of time) and also to account for all field sources in the vicinity of the measurements.

As with electric fields, the maximum or peak magnetic fields occur in areas near the centerline and at midspan where the conductors are the lowest. The magnetic field at the edge of the right-of-way is not very dependent on line height. If more than one line is present, the peak field will depend on the relative electrical phasing of the conductors and the direction of power flow.

4.3 Calculated Values for Magnetic Fields

Table 4 gives the calculated values of the magnetic field at 3.28 ft. (1 m) height for the proposed 500-kV transmission line configurations. Field values on the right-of-way and at the edge of the right-of-way are given for projected maximum currents during system annual peak load in 2004, for minimum and average conductor clearances. The maximum currents are 1758 A on each of the three phases of the proposed line. The actual magnetic-field levels would vary, as currents on the lines change daily and seasonally and as ambient temperature changes. Average currents over the year would be about 50% of the maximum values. The levels shown in the figures represent the highest magnetic fields expected for the proposed McNary – John Day 500-kV line. Average fields over a year would be considerably reduced from the peak values, as a result of increased clearances above the minimum value and reduced currents from the maximum value.

Figure 3 shows lateral profiles of the magnetic field under maximum current and minimum clearance conditions for configurations of the proposed 500-kV transmission line. A field profile for average height under Configuration 3 is also included in Figure 3c. Maximum field levels for the existing configurations are also shown in Figure 3.

For the proposed 500-kV line, the maximum calculated 60-Hz magnetic field expected at 3.28 ft. (1 m) above ground is 311 mG. This field is calculated for the maximum current of 1758 A, with the conductors at a height of 35 ft. (10.7 m). The maximum field would decrease for increased conductor clearance. For an average conductor height over a span of 45 ft. (13.7 m), the maximum field would be 216 mG. Maximum fields under the proposed line in the configuration with no immediately adjacent parallel lines would be slightly less than these values.

The magnetic field at the edge of the right-of-way depends on the width of the right-of-way which varies considerably for the proposed line. For maximum current conditions the calculated magnetic field at the edge of the right-of-way varies from 89 mG to 16 mG as the center line to edge of right-of-way distance varies from 72.5 ft. to 175 ft. The field at the edge of the right-of-way adjacent to a parallel line would depend on that line.

The magnetic field falls off rapidly as distance from the line increases. At a distance of 225 ft. (69 m) from the centerline of the proposed line with no parallel lines, the field would be less than 10 mG for maximum current conditions.

For the existing lines, the peak magnetic fields on the rights-of-way are 327 mG and 298 mG, for the 500-kV and 230-kV lines, respectively. The peak value of 327 mG occurs under the existing Hanford – John Day 500-kV line. Fields at the edges of the existing rights-of-way range from 84 mG for the McNary – Horse Heaven 230-kV line to 9 mG for the Hanford – John Day 500-kV line which is 220 ft. from the edge of the right-of-way.

4.4 Environmental Magnetic Fields

Transmission lines are not the only source of magnetic fields; as with 60-Hz electric fields, 60-Hz magnetic fields are present throughout the environment of a society that relies on electricity as a principal energy source. The magnetic fields associated with the proposed McNary – John Day 500-kV line can be compared with fields from other sources. The range of 60-Hz magnetic-field exposures in publicly accessible locations such as open spaces, transmission-line rights-of-way, streets, pedestrian walkways, parks, shopping malls, parking lots, shops, hotels, public transportation, and so on range from less than 0.1 mG to about 1 G, with the highest values occurring near small appliances with electric motors. In occupational settings in electric utilities, where high currents are present, magnetic-field exposures for workers can be above 1 G. At 60 Hz, the magnitude of the natural magnetic field is approximately 0.0005 mG.

Several investigations of residential fields have been conducted. In a large study to identify and quantify significant sources of 60-Hz magnetic fields in residences, measurements were made in 996 houses, randomly selected throughout the country (Zaffanella, 1993). The most common sources of residential fields were power lines, the grounding system of residences, and appliances. Field levels were characterized by both point-in-time (spot) measurements and 24-hour measurements. Spot measurements averaged over all rooms in a house exceeded 0.6 mG in 50% of the houses and 2.9 mG in 5% of houses. Power lines generally produced the largest average fields in a house over a 24-hour period. On the other hand, grounding system currents proved to be a more significant source of the highest fields in a house. Appliances were found to produce the highest local fields; however, fields fell off rapidly with increased distance. For example, the median field near microwave ovens was 36.9 mG at a distance of 10.5 in (0.27 m) and 2.1 mG at 46 in (1.17 m). Across the entire sample of 996 houses, higher magnetic fields were found in, among others, urban areas (vs. rural); multi-unit dwellings (vs. single-family); old houses (vs. new); and houses with grounding to a municipal water system.

In an extensive measurement project to characterize the magnetic-field exposure of the general population, over 1000 randomly selected persons in the United States wore a personal exposure meter for 24 hours and recorded their location in a simple diary (Zaffanella and Kalton, 1998). Based on the measurements of 853 persons, the estimated 24-hour average exposure for the general population is 1.24 mG and the estimated median exposure is 0.88 mG. The average field “at home, not in bed” is 1.27 mG and “at home, in bed” is 1.11 mG. Average personal exposures were found to be largest “at work” (mean of 1.79 mG and median of 1.01 mG) and lowest “at home, in bed” (mean of 1.11 mG and median of 0.49 mG). Average fields in school were also low (mean of 0.88 mG and median of 0.69 mG). Factors associated with higher exposures at home were smaller residences, duplexes and apartments, metallic rather than plastic water pipes, and nearby overhead distribution lines.

As noted above, magnetic fields from appliances are localized and decrease rapidly with distance from the source. Localized 60-Hz magnetic fields have been measured near about 100 household appliances such as ranges, refrigerators, electric drills, food mixers, and shavers (Gauger, 1985). At a distance of 1 ft. (0.3 m), the maximum magnetic field ranged from 0.3 to 270 mG, with 95% of the measurements below 100 mG. Ninety-five percent of the levels at a distance of 4.9 ft. (1.5 m) were less than 1 mG. Devices that use light-weight, high-torque motors with little magnetic shielding exhibited the largest fields. These included vacuum cleaners and small hand-held appliances and tools. Microwave ovens with large power transformers also exhibited relatively large fields. Electric blankets have been a much-studied source of magnetic-field exposure because of the length of time they are used and because of the close proximity to the body. Florig and Hoburg (1988) estimated that the average magnetic field in a person using an electric blanket was 15 mG, and that the maximum field could be 100 mG. New "low-field" blankets have magnetic fields at least 10 times lower than those from conventional blankets (Bassen et al., 1991).

In a domestic magnetic-field survey, Silva et al. (1989) measured fields near different appliances at locations typifying normal use (e.g., sitting at an electric typewriter or standing at a stove). Specific appliances with relatively large fields included can openers (n = 9), with typical fields ranging from 30 to 225 mG and a maximum value up to 2.7 G; shavers (n = 4), with typical fields from 50 to 300 mG and maximum fields up to 6.9 G; and electric drills (n = 2), with typical fields from 56 to 190 mG and maximum fields up to 1.5 G. The fields from such appliances fall off very rapidly with distance and are only present for short periods. Thus, although instantaneous magnetic-field levels close to small hand-held appliances can be quite large, they do not contribute to average area levels in residences.

Although studies of residential magnetic fields have not all considered the same independent parameters, the following consistent characterization of residential magnetic fields emerges from the data:

(1) External sources play a large role in determining residential magnetic-field levels. Transmission lines, when nearby, are an important external source. Unbalanced ground currents on neutral conductors and other conductors, such as water pipes in and near a house, can represent a significant source of magnetic field. Distribution lines per se, unless they are quite close to a residence, do not appear to be a traditional distance-dependent source.

(2) Homes with overhead electrical service appear to have higher average fields than those with underground service.

(3) Appliances represent a localized source of magnetic fields that can be much higher than average or area fields. However, fields from appliances approach area levels at distances greater than 3.28 ft. (1 m) from the device.

Although important variables in determining residential magnetic fields have been identified, quantification and modeling of their influence on fields at specific locations is not yet possible. However, a general characterization of residential magnetic-field level is possible: average levels in the United States are in the range of 0.5 to 1.0 mG, with the average field in a small number of homes exceeding this range by as much as a factor of 10 or more. Average personal exposure levels are slightly higher, possibly due to use of appliances and varying distances to other sources. Maximum fields can be much higher.

Magnetic fields in commercial and retail locations are comparable with those in residences. As with appliances, certain equipment or machines can be a local source of higher magnetic fields. Utility workers who work close to transformers, generators, cables, transmission lines, and distribution systems clearly experience high-level fields. Other sources of fields in the workplace include motors, welding machines, computers, and video display terminals (VDTs). In publicly accessible indoor areas, such as offices and stores, field levels are generally comparable with residential levels, unless a high-current source is nearby.

Because high-current sources of magnetic field are more prevalent than high-voltage sources, occupational environments with relatively high magnetic fields encompass a more diverse set of occupations than do those with high electric fields. For example, in occupational magnetic-field measurements reported by Bowman et al. (1988), the geometric mean field from 105 measurements of magnetic field in "electrical worker" job locations was 5.0 mG. "Electrical worker" environments showed the following elevated magnetic-field levels (geometric mean greater than 20 mG): industrial power supplies, alternating current (ac) welding machines, and sputtering systems for electronic assembly. For secretaries in the same study, the geometric mean field was 3.1 mG for those using VDTs (n = 6) and 1.1 mG for those not using VDTs (n = 3).

Measurements of personal exposure to magnetic fields were made for 1,882 volunteer utility workers for a total of 4,411 workdays (Bracken, 1990). Median workday mean exposures ranged from 0.5 mG for clerical workers without computers to 7.2 mG for substation operators. Occupations not specifically associated with transmission and distribution facilities had median workday exposures less than 1.5 mG, while those associated with such facilities had median exposures above 2.3 mG. Magnetic-field exposures measured in homes during this study were comparable with those recorded in offices.

Magnetic fields in publicly accessible outdoor areas seem to be, as expected, directly related to proximity to electric-power transmission and distribution facilities. Near such facilities, magnetic fields are generally higher than indoors (residential). Higher-voltage facilities tend to have higher fields. Typical maximum magnetic fields in publicly accessible areas near transmission facilities can range from less than a few milligauss up to 300 mG or more, near heavily loaded lines operated at 230 to 765 kV. The levels depend on the line load, conductor height, and location on the right-of-way. Because magnetic fields near high-voltage transmission lines depend on the current in the line, they can vary daily and seasonally. To characterize fields from the distribution system, Heroux (1987) measured 60-Hz magnetic fields with a mobile platform along 140 mi. (223 km) of roads in Montreal. The median field level averaged over nine different routes was 1.6 mG, with 90% of the measurements less than about 5.1 mG. Spot measurements indicated that typical fields directly above underground distribution systems were 5 to 19 mG. Beneath overhead distribution lines, typical fields were 1.5 to 5 mG on the primary side of the transformer, and 4 to 10 mG on the secondary side. Near ground-based transformers used in residential areas, fields were 80 to 1000 mG at the surface and 10 to 100 mG at a distance of 1 ft. (0.3 m).

The magnetic fields from the proposed line would be comparable to or less than those from existing 500-kV lines in Oregon, Washington, and elsewhere. On and near the right-of-way of the proposed line, magnetic fields would be well above average residential levels. However, the fields from the line would decrease rapidly and approach common ambient levels at distances greater than a few hundred feet from the line. Furthermore, the fields at the edge of the right-of-way would not be above those encountered during normal activities near common sources such as hand-held appliances.

5.0 Electric and Magnetic Field (EMF) Effects

Possible effects associated with the interaction of EMF from transmission lines with people on and near a right-of-way fall into two categories: short-term effects that can be perceived and may represent a nuisance, and possible long-term health effects. Only short-term effects are discussed here. The issue of whether there are long-term health effects associated with transmission-line fields is controversial. In recent years, considerable research on possible biological effects of EMF has been conducted. A review of these studies and their implications for health-related effects is provided in a separate technical report for the environmental assessment for the proposed McNary – John Day 500-kV transmission line.

5.1 Electric Fields: Short-term Effects

Short-term effects from transmission-line electric fields are associated with perception of induced currents and voltages or perception of the field. Induced current or spark discharge shocks can be experienced under certain conditions when a person contacts objects in an electric field. Such effects occur in the fields associated with transmission lines that have voltages of 230-kV or higher. These effects could occur infrequently under the proposed McNary – John Day 500-kV line.

Steady-state currents are those that flow continuously after a person contacts an object and provides a path to ground for the induced current. The amplitude of the steady-state current depends on the induced current to the object in question and on the grounding path. The magnitude of the induced current to vehicles and objects under the proposed line will depend on the electric-field strength and the size and shape of the object. When an object is electrically grounded, the voltage on the object is reduced to zero, and it is not a source of current or voltage shocks. If the object is poorly grounded or not grounded at all, then it acquires some voltage relative to earth and is a possible source of current or voltage shocks.

The responses of persons to steady-state current shocks have been extensively studied, and levels of response documented (Keesey and Letcher, 1969; IEEE, 1978). Primary shocks are those that can result in direct physiological harm. Such shocks will not be possible from induced currents under the existing or proposed lines, because clearances above ground required by the NESC preclude such shocks from large vehicles and grounding practices eliminate large stationary objects as sources of such shocks.

Secondary shocks are defined as those that could cause an involuntary and potentially harmful movement, but no direct physiological harm. Secondary shocks could occur under the proposed 500-kV line when making contact with ungrounded conducting objects such as vehicles or equipment. However, such occurrences are anticipated to be very infrequent. Shocks, when they occur under the 500-kV line, are most likely to be below the nuisance level. Induced currents are extremely unlikely to be perceived off the right-of-way of the proposed line.

Induced currents are always present in electric fields under transmission lines and will be present near the proposed line. However, during initial construction, BPA routinely grounds metal objects that are located on or near the right-of-way. The grounding eliminates these objects as sources of induced current and voltage shocks. Multiple grounding points are used to provide redundant paths for induced current flow. After construction, BPA would respond to any complaints and install or repair grounding to mitigate nuisance shocks.

Unlike fences or buildings, mobile objects such as vehicles and farm machinery cannot be grounded permanently. Limiting the possibility of induced currents from such objects to persons is accomplished in several ways. First, required clearances for above-ground conductors tend to limit field strengths to levels that do not represent a hazard or nuisance. The NESC (IEEE, 2002) requires that, for lines with voltage exceeding 98 kV line-to-ground (170 kV line-to-line), sufficient conductor clearance be maintained to limit the induced short-circuit current in the largest anticipated vehicle under the line to 5 milliamperes (mA) or less. This can be accomplished by limiting access or by increasing conductor clearances in areas where large vehicles could be present. BPA and other utilities design and operate lines to be in compliance with the NESC.

For the proposed line, conductor clearances (50°C conductor temperature) would be increased to at least 54 ft. (16.5 m) over major road crossings along the route, resulting in a maximum field of 4.4 kV/m or less at the 3.28 ft. (1 m) height. The largest truck allowed on roads in Oregon and Washington without a special permit is 14 ft. high by 8.5 ft. wide by 75 ft. long (4.3 x 2.6 x 22.9 m). The induced currents to such a vehicle oriented perpendicular to the line in a maximum field of 4.2 kV/m (at 3.28-ft. height) would be less than 4.0 mA (Reilly, 1979). For smaller trucks, the maximum induced currents for perpendicular orientation to the proposed line would be less than this value. (Larger special-permitted trucks, such as triple trailers, can be up to 105 feet in length. However, because they average the field over such a long distance, the maximum induced current to a 105-ft. vehicle oriented perpendicular to the 500-kV line at a road crossing would be less than 3.8 mA.) Thus, the NESC 5-mA criterion would be met for perpendicular road crossings of the proposed line. These large vehicles are not anticipated to be off highways or oriented parallel to the proposed line. As discussed below, these are worst-case estimates of induced currents at road crossings; conditions for their occurrence are rare. The conductor clearance at each road crossing would be checked during the design stage of the line to ensure that the NESC 5-mA criterion is met. Furthermore, it is BPA policy to limit the maximum induced current from vehicles to 2 mA in commercial parking lots. Line clearances would also be increased in accordance with the NESC, such as over railroads and water areas suitable for sailboating.

Several factors tend to reduce the levels of induced current shocks from vehicles:

(1) Activities are distributed over the whole right-of-way, and only a small percentage of time is spent in areas where the field is at or close to the maximum value.

(2) At road crossings, vehicles are aligned perpendicular to the conductors, resulting in a substantial reduction in induced current.

(3) The conductor clearance at road crossings may not be at minimum values because of lower conductor temperatures and/or location of the road crossing away from midspan.

(4) The largest vehicles are permitted only on certain highways.

(5) Off-road vehicles are in contact with soil or vegetation, which reduces shock currents substantially.

Induced voltages occur on objects, such as vehicles, in an electric field where there is an inadequate electrical ground. If the voltage is sufficiently high, then a spark discharge shock can occur as contact is made with the object. Such shocks are similar to "carpet" shocks that occur, for example, when a person touches a doorknob after walking across a carpet on a dry day. The number and severity of spark discharge shocks depend on electric-field strength. Based on the low frequency of complaints reported by Glasgow and Carstensen (1981) for 500-kV alternating current transmission lines (one complaint per year for each 1,500 mi. or 2400 km of 500-kV line), nuisance shocks, which are primarily spark discharges, do not appear to be a serious impediment to normal activities under 500-kV lines.

In electric fields higher than will occur under the proposed line, it is theoretically possible for a spark discharge from the induced voltage on a large vehicle to ignite gasoline vapor during refueling. The probability for exactly the right conditions for ignition to occur is extremely remote. The additional clearance of conductors provided at road crossings reduces the electric field in areas where vehicles are prevalent and reduces the chances for such events. Even so, BPA recommends that vehicles should not be refueled under the proposed line unless specific precautions are taken to ground the vehicle and the fueling source (USDOE, 1995).

Under certain conditions, the electric field can be perceived through hair movement on an upraised hand or arm of a person standing on the ground under high-voltage transmission lines. The median field for perception in this manner was 7 kV/m for 136 persons; only about 12% could perceive fields of 2 kV/m or less (Deno and Zaffanella, 1982). In areas under the conductors at midspan, the fields at ground level would exceed the levels where field perception normally occurs. In these instances, field perception could occur on the right-of-way of the proposed line. It is unlikely that the field would be perceived beyond the edge of the right-of-way. Where vegetation provides shielding, the field would not be perceived.

Conductive shielding reduces both the electric field and induced effects such as shocks. Persons inside a vehicle cab or canopy are shielded from the electric field. Similarly, a row of trees or a lower-voltage distribution line reduces the field on the ground in the vicinity. Metal pipes, wiring, and other conductors in a residence or building shield the interior from the transmission-line electric field.

The electric fields from the proposed 500-kV line would be comparable to those from existing 500-kV lines in the project area and elsewhere. Potential impacts of electric fields can be mitigated through grounding policies, adherence to the NESC, and increased clearances above the minimums specified by the NESC. Worst-case levels are used for safety analyses but, in practice, induced currents and voltages are reduced considerably by unintentional grounding. Shielding by conducting objects, such as vehicles and vegetation, also reduces the potential for electric-field effects.

5.2 Magnetic Field: Short-term Effects

Magnetic fields associated with transmission and distribution systems can induce voltage and current in long conducting objects that are parallel to the transmission line. As with electric-field induction, these induced voltages and currents are a potential source of shocks. A fence, irrigation pipe, pipeline, electrical distribution line, or telephone line forms a conducting loop when it is grounded at both ends. The earth forms the other portion of the loop. The magnetic field from a transmission line can induce a current to flow in such a loop if it is oriented parallel to the line. If only one end of the fence is grounded, then an induced voltage appears across the open end of the loop. The possibility for a shock exists if a person closes the loop at the open end by contacting both the ground and the conductor. The magnitude of this potential shock depends on the following factors: the magnitude of the field; the length of the object (the longer the object, the larger the induced voltage); the orientation of the object with respect to the transmission line (parallel as opposed to perpendicular, where no induction would occur); and the amount of electrical resistance in the loop (high resistance limits the current flow).

Magnetically induced currents from power lines have been investigated for many years; calculation methods and mitigating measures are available. A comprehensive study of gas pipelines near transmission lines developed prediction methods and mitigation techniques specifically for induced voltages on pipelines (Dabkowski and Taflove, 1979; Taflove and Dabkowski, 1979). Similar techniques and procedures are available for irrigation pipes and fences. Grounding policies employed by utilities for long fences reduce the potential magnitude of induced voltage.

The magnitude of the coupling with both pipes and fences is very dependent on the electrical unbalance (unequal currents) among the three phases of the line. Thus, a distribution line where a phase outage may go unnoticed for long periods of time can represent a larger source of induced currents than a transmission line where the loads are well-balanced (Jaffa and Stewart, 1981).

Knowledge of the phenomenon, grounding practices, and the availability of mitigation measures mean that magnetic-induction effects from the proposed 500-kV transmission line will be minimal. In addition, the proposed line would be located in an existing corridor where mitigation measures will have already been implemented for the existing lines.

Magnetic fields from transmission and distribution facilities can interfere with certain electronic equipment. Magnetic fields can cause distortion of the image on VDTs and computer monitors. The threshold field for interference depends on the type and size of monitor and the frequency of the field. Interference has been observed for certain monitors at fields at or below 10 mG (Baishiki et al., 1990; Banfai et al., 2000). Generally, the problem arises when computer monitors are in use near electrical distribution facilities in large office buildings. Fields from the proposed line would fall below this level at approximately 225 ft. (69 m) from the centerline.

Interference from magnetic fields can be eliminated by shielding the affected monitor or moving it to an area with lower fields. Similar mitigation methods could be applied to other sensitive electronics, if necessary. Interference from 60-Hz fields with computers and control circuits in vehicles and other equipment is not anticipated at the field levels found under and near the proposed 500-kV transmission line.

The magnetic fields from the proposed line would be comparable to those from existing 500-kV lines in the area of the proposed line.

6.0 Regulations

Regulations that apply to transmission-line electric and magnetic fields fall into two categories. Safety standards or codes are intended to limit or eliminate electric shocks that could seriously injure or kill persons. Field limits or guidelines are intended to limit electric- and magnetic-field exposures that can cause nuisance shocks or <u>might</u> cause health effects. In no case has a limit or standard been established because of a known or demonstrated health effect.

The proposed line would be designed to meet the NESC (IEEE, 2002), which specifies how far transmission-line conductors must be from the ground and other objects. The clearances specified in the code provide safe distances that prevent harmful shocks to workers and the public. In addition, people who live and work near transmission lines must be aware of safety precautions to avoid electrical (which is not necessarily physical) contact with the conductors. For example, farmers should not up-end irrigation pipes under a transmission or other electrical line or direct the water stream from an irrigation system into or near the conductors. In addition, as a matter of safety, the NESC specifies that electric-field-induced currents from transmission lines must be below the 5 mA ("let go") threshold deemed a lower limit for primary shock. BPA publishes and distributes a brochure that describes safe practices to protect against shock hazards around power lines (USDOE, 1995).

Field limits or guidelines have been adopted in several states and countries and by national and international organizations. Electric-field limits have generally been based on minimizing nuisance shocks or field perception. The intent of magnetic-field limits has been to limit exposures to existing levels, given the uncertainty of their potential for health effects.

There are currently no national standards in the United States for 60-Hz electric and magnetic fields. Oregon's formal rule in its transmission-line-siting procedures specifically addresses field limits. The Oregon limit of 9 kV/m for electric fields is applied to areas accessible to the public (Oregon, State of, 1980). The Oregon rule also addresses grounding practices, audible noise, and radio interference. Oregon does not have a limit for magnetic fields from transmission lines. The state of Washington does not have guidelines for electric or magnetic fields from transmission lines.

Besides Oregon, several states have been active in establishing mandatory or suggested limits on 60-Hz electric and (in two cases) magnetic fields. Five other states have specific electric-field limits that apply to transmission lines: Florida, Minnesota, Montana, New Jersey, and New York. Florida and New York have established regulations for magnetic fields. These regulations are summarized in Table 5, adapted from TDHS Report (1989).

Government agencies and utilities operating transmission systems have established design criteria that include EMF levels. BPA has maximum allowable electric fields of 9 and 5 kV/m on and at the edge of the right-of-way, respectively (USDOE, 1996). BPA also has maximum-allowable electric field strengths of 5 kV/m, 3.5 kV/m, and 2.5 kV/m for road crossings, shopping center parking lots, and commercial/industrial parking lots, respectively. These levels are based on limiting the maximum short-circuit currents from anticipated vehicles to less than 1 mA in shopping center lots and to less than 2 mA in commercial parking lots.

Electric-field limits for overhead power lines have also been established in other countries (Maddock, 1992). Limits for magnetic fields from overhead power lines have not been explicitly established anywhere except in Florida and New York (see Table 5). However, general guidelines and limits on EMF have been established for occupational and public exposure in several countries and by national and international organizations.

The American Conference of Governmental Industrial Hygienists (ACGIH) sets guidelines (Threshold Limit Values or TLV) for occupational exposures to environmental agents (ACGIH, 2000). In general, a TLV represents the level below which it is believed that nearly all workers may be exposed repeatedly without adverse health effects. For EMF, the TLVs represent ceiling levels. For 60-Hz electric fields, occupational exposures should not exceed the TLV of 25 kV/m. However, the ACGIH also recognizes the potential for startle reactions from spark discharges and short-circuit currents in fields greater than 5-7 kV/m, and recommends implementing grounding practices. They recommend the use of conductive clothing for work in fields exceeding 15 kV/m. The TLV for occupational exposure to 60-Hz magnetic fields is a ceiling level of 10 G (10,000 mG) (ACGIH, 2000).

Electric and magnetic fields from various sources (including automobile ignitions, appliances and, possibly, transmission lines) can interfere with implanted cardiac pacemakers. In light of this potential problem, manufacturers design devices to be immune from such interference. However, research has shown that these efforts have not been completely successful and that a few models of pacemakers could be affected by 60-Hz fields from transmission lines. There were also numerous models of pacemakers that were not affected by fields even larger than those found under transmission lines. Because of the known potential for interference with pacemakers by 60-Hz fields, field limits for pacemaker wearers have been established by the ACGIH. They recommend that wearers of pacemakers and similar medical-assist devices limit their exposure to electric fields of 1 kV/m or less and to magnetic fields to 1 G (1,000 mG) or less (ACGIH, 2000).

The International Committee on Non-ionizing Radiation Protection (ICNIRP), working in cooperation with the World Health Organization (WHO), has developed guidelines for occupational and public exposures to EMF (ICNIRP, 1998). For occupational exposures at 60 Hz, the recommended limits to exposure are 8.3 kV/m for electric fields and 4.2 G (4,200 mG) for magnetic fields. The electric-field level can be exceeded, provided precautions are taken to prevent spark discharge and induced current shocks. For the general public, the ICNIRP guidelines recommend exposure limits of 4.2 kV/m for electric fields and 0.83 G (830 mG) for magnetic fields (ICNIRP, 1998).

ICNIRP has also established guidelines for contact currents, which could occur when a grounded person contacts an ungrounded object in an electric field. The guideline levels are 1.0 mA for occupational exposure and 0.5 mA for public exposure.

The electric fields from the proposed 500-kV line would meet the ACGIH standards, provided wearers of pacemakers and similar medical-assist devices are discouraged from unshielded right-of-way use. (A passenger in an automobile under the line would be shielded from the electric field.) The electric fields in limited areas on the right-of-way would exceed the ICNIRP guideline for public exposure. The magnetic fields from the proposed line would be below the ACGIH limits, as well as below those of ICNIRP. The electric fields present on the right-of-way could induce currents in ungrounded vehicles that exceeded the ICNIRP level of 0.5 mA.

The estimated peak electric fields on the right-of-way of the proposed transmission line would meet the Oregon limit as well as those set in Florida and New York, but not those of Minnesota and Montana (see Table 5). The BPA maximum allowable electric field-limit would be met for all configurations of the proposed line. The edge-of-right-of-way electric fields from the proposed line would be below limits set in New Jersey, but above those in Florida, Montana, and New York.

The magnetic field at the edge of the right-of-way from the proposed line would be below the regulatory levels of states where such regulations exist.

7.0 Audible Noise

7.1 Basic Concepts

Audible noise (AN), as defined here, represents an unwanted sound, as from a transmission line, transformer, airport, or vehicle traffic. Sound is a pressure wave caused by a sound source vibrating or displacing air. The ear converts the pressure fluctuations into auditory sensations. AN from a source is superimposed on the background or ambient noise that is present before the source is introduced.

The amplitude of a sound wave is the incremental pressure resulting from sound above atmospheric pressure. The sound-pressure level is the fundamental measure of AN; it is generally measured on a logarithmic scale with respect to a reference pressure. The sound-pressure level (SPL) in decibels (dB) is given by:

$$SPL = 20 \log (P/P_o) dB$$

where P is the effective rms (root-mean-square) sound pressure, P_O is the reference pressure, and the logarithm (log) is to the base 10. The reference pressure for measurements concerned with hearing is usually taken as 20 micropascals (Pa), which is the approximate threshold of hearing for the human ear. A logarithmic scale is used to encompass the wide range of sound levels present in the environment. The range of human hearing is from 0 dB up to about 140 dB, a ratio of 10 million in pressure (EPA, 1978).

Logarithmic scales, such as the decibel scale, are not directly additive: to combine decibel levels, the dB values must be converted back to their respective equivalent pressure values, the total rms pressure level found, and the dB value of the total recalculated. For example, adding two sounds of equal level on the dB scale results in a 3 dB increase in sound level. Such an increase in sound pressure level of 3 dB, which corresponds to a doubling of the energy in the sound wave, is barely discernible by the human ear. It requires an increase of about 10 dB in SPL to produce a subjective doubling of sound level for humans. The upper range of hearing for humans (140 dB) corresponds to a sharply painful response (EPA, 1978).

Humans respond to sounds in the frequency range of 16 to 20,000 Hz. The human response depends on frequency, with the most sensitive range roughly between 2000 and 4000 Hz. The frequency-dependent sensitivity is reflected in various weighting scales for measuring audible noise. The A-weighted scale weights the various frequency components of a noise in approximately the same way that the human ear responds. This scale is generally used to measure and describe levels of environmental sounds such as those from vehicles or occupational sources. The A-weighted scale is also used to characterize transmission-line noise. Sound levels measured on the A-scale are expressed in units of dB(A) or dBA.

AN levels and, in particular, corona-generated audible noise (see below) vary in time. In order to account for fluctuating sound levels, statistical descriptors have been developed for environmental noise. Exceedence levels (L levels) refer to the A-weighted sound level that is exceeded for a specified percentage of the time. Thus, the L_5 level refers to the noise level that is exceeded only 5% of the time. L_{50} refers to the sound level exceeded 50% of the time. Sound-level measurements and predictions for transmission lines are often expressed in terms of exceedence levels, with the L_5 level representing the maximum level and the L_{50} level representing a median level.

Table 6 shows AN levels from various common sources. Clearly, there is wide variation. Noise exposure depends on how much time an individual spends in different locations. Outdoor noise generally does not contribute to indoor levels (EPA, 1974). Activities in a building or residence generally dominate interior AN levels. The amount of sound attenuation (reduction) provided by buildings is given in Table 7. Assuming that residences along the line route fall in the "warm climate, windows open" category, the typical sound attenuation provided by a house is about 12 dBA.

The BPA design criterion for corona-generated audible noise (L_{50}, foul weather) is 50 ±2 dBA at the edge of the ROW (Perry, 1982). This criterion has been interpreted by the state and BPA to meet Oregon Noise Control Regulations (Perry, 1982). The Washington Administrative Code provides noise limitations by class of property, residential, commercial or industrial (Washington, State of, 1975). Transmission lines are classified as industrial and may cause a maximum permissible noise level of 60 dBA to intrude into residential property. During nighttime hours (10:00 p.m. to 7:00 a.m.), the maximum permissible limit for noise from industrial to residential areas is reduced to 50 dBA. This latter level applies to transmission lines that operate continuously. The state of Washington Department of Ecology accepts the 50 dBA level at the edge of the right-of-way for transmission lines, but encouraged BPA to design lines with lower audible noise levels (WDOE, 1981).

The EPA has established a guideline of 55 dBA for the annual average day-night level (L_{dn}) in outdoor areas (EPA, 1978). In computing this value, a 10 dB correction (penalty) is added to night-time noise between the hours of 10 p.m. and 7 a.m.

7.2 Transmission-line Audible Noise

Corona is the partial electrical breakdown of the insulating properties of air around the conductors of a transmission line. In a small volume near the surface of the conductors, energy and heat are dissipated. Part of this energy is in the form of small local pressure changes that result in audible noise. Corona-generated audible noise can be characterized as a hissing, crackling sound that, under certain conditions, is accompanied by a 120-Hz hum. Corona-generated audible noise is of concern primarily for contemporary lines operating at voltages of 345 kV and higher during foul weather. The proposed 500-kV line will produce some noise under foul weather conditions.

The conductors of high-voltage transmission lines are designed to be corona-free under ideal conditions. However, protrusions on the conductor surface—particularly water droplets on or dripping off the conductors—cause electric fields near the conductor surface to exceed corona onset levels, and corona occurs. Therefore, audible noise from transmission lines is generally a foul-weather (wet-conductor) phenomenon. Wet conductors can occur during periods of rain, fog, snow, or icing. Based on meteorologic records near the route of the proposed transmission line, such conditions are expected to occur only about 1% of the time during the year.

For a few months after line construction, residual grease or oil on the conductors can cause water to bead up on the surface. This results in more corona sources and slightly higher levels of audible noise and electromagnetic interference if the line is energized. However, the new conductors "age" in a few months, and the level of corona activity decreases to the predicted equilibrium value. During fair weather, insects and dust on the conductor can also serve as sources of corona. The proposed line has been designed with three 1.3-inch (3.30-cm) diameter conductors per phase, which will yield acceptable corona levels.

7.3 Predicted Audible Noise Levels

Audible noise levels are calculated for average voltage and average conductor heights for fair- and foul-weather conditions. The predicted levels of corona-generated audible noise for the proposed line operated at a voltage of 540 kV are given in Table 8 and plotted in Figure 4 for the proposed configurations. For comparison, Table 8 also gives the calculated levels for the existing parallel lines.

The calculated median level (L_{50}) during foul weather 75 feet from the centerline of the proposed McNary – John Day right-of-way with <u>no</u> parallel lines is 47 dBA; the calculated maximum level (L_5) during foul weather at this location is 51 dBA. These levels are comparable with levels at the edges of some existing 500-kV lines in Oregon and Washington and lower than the levels from the existing Hanford – John Day 500-kV line in the corridor. However, for all the proposed configurations the resulting AN levels are higher than these because of contributions from existing lines.

For the configurations with immediately adjacent parallel lines (Configurations 1, 2 and 4), the foul weather L_{50} AN level at the edge of the right-of-way adjacent to the proposed line would be 49 to 54 dBA. In these cases, AN from the existing parallel 345-kV and/or 500-kV lines is comparable to or greater than that from the proposed line; and the proposed line would add 4 dBA or less to existing noise levels at the proposed edge of the right-of-way. Such an increase would be barely discernible. Even for Configuration 3 where the proposed line would be more than 600 feet from the existing 345-kV line, the proposed line would add only about 6 dBA to existing levels. At the edge of the right-of-way adjacent to the existing lines in the corridor, the foul weather L_{50} AN level would change 1 dBA or less with the addition of the proposed line.

During fair-weather conditions, which occur about 99% of the time, audible noise levels at the edge of the right-of-way would be about 20 dBA lower than the foul weather levels (if corona were present). These lower levels could be masked by ambient noise on and off the right-of-way.

7.4 Discussion

The calculated foul-weather corona noise levels for the proposed line with no parallel lines would be comparable to, or less, than those from existing 500-kV lines in Oregon and Washington. During fair weather, noise from the conductors might be perceivable on the right-of-way, but beyond the right-of-way it would likely be masked or so low as not to be perceived, even during foul weather when ambient noise is higher.

Where the proposed line parallels the existing lines, the increase of less than 4 dBA due to the addition of the proposed line would barely be discernible at the edge of the right of-way and beyond. The level at the edge of the right-of-way of the existing lines would be the same, whether the proposed line were present or not.

No transformers are being added to the existing McNary and John Day Substations. Noise from the existing substation equipment and transmission lines would remain the primary source of environmental noise at these locations. The large-diameter tubular conductors in the station do not generate corona noise during fair weather and any noise generated during foul weather would be masked by noise from the transmission lines entering and leaving the station. During foul weather the noise from the proposed and existing lines would mask the substation noise at the outer edges of the rights-of-way.

Off the right-of-way, the levels of audible noise from the proposed line during foul weather would be below the 55 dBA level that can produce interference with speech outdoors. Since residential buildings provide significant sound attenuation (-12 dBA with windows open; -24 dBA with windows closed), the noise levels off the right-of-way would be well below the 45 dBA level required for interference with speech indoors and below the 35 dBA level where sleep interference can occur (EPA, 1973; EPA, 1978). Since corona is a foul-weather phenomenon, people tend to be inside with windows possibly closed, providing additional attenuation when corona noise is present. In addition, ambient noise levels can be high during such periods (due to rain hitting foliage or buildings), and can mask corona noise.

The 47-dBA level for the proposed line would meet the BPA design criterion and, hence, the Oregon regulations and the Washington Administrative Code limits for transmission lines. Noise levels at the edges of the rights-of-way of the existing McNary – Ross 345-kV and Hanford – John Day 500-kV lines (not shown in Table 8) exceed the limits of both Oregon and Washington and presumably are allowed because of the ages of the lines.

The computed annual L_{dn} level for transmission lines operating in areas with about 1% foul weather is about $L_{dn} = L_{50}$ - 6 dB (Bracken, 1987). Therefore, assuming such conditions in the area of the proposed McNary – John Day 500-kV line, the estimated L_{dn} at the edge of the right-of-way would be approximately 48 dBA or less, which is well below the EPA L_{dn} guideline of 55 dBA.

7.5 Conclusion

Along the proposed line route where no parallel lines are within 600 feet, there would be increases in the perceived noise above ambient levels during foul weather at the edges of the right-of-way. Where the proposed line parallels the existing 345-kV or 500-kV lines, the incremental noise contributed by the proposed line would be less than 4 dBA at the edge of the proposed new right-of-way and beyond, and would probably not be discernible from existing noise levels.

The corona-generated noise during foul weather would be masked to some extent by naturally occurring sounds such as wind and rain on foliage. During fair weather, the noise off the right-of-way from the proposed line would probably not be detectable above ambient levels. The noise levels from the proposed line would be below levels identified as causing interference with speech or sleep. The audible noise from the transmission line would be below EPA guideline levels and would meet the BPA design criterion that complies with the Oregon and Washington state noise regulations.

8.0 Electromagnetic Interference

8.1 Basic Concepts

Corona on transmission-line conductors can also generate electromagnetic noise in the frequency bands used for radio and television signals. The noise can cause radio and television interference (RI and TVI). In certain circumstances, corona-generated electromagnetic interference (EMI) can also affect communications systems and other sensitive receivers. Interference with electromagnetic signals by corona-generated noise is generally associated with lines operating at voltages of 345 kV or higher. This is especially true of interference with television signals. The bundle of three 1.3-in. diameter conductors used in the design of the proposed 500-kV line would mitigate corona generation and thus keep radio and television interference levels at acceptable levels.

Spark gaps on distribution lines and on low-voltage wood-pole transmission lines are a more common source of RI/TVI than is corona from high-voltage electrical systems. This gap-type interference is primarily a fair-weather phenomenon caused by loose hardware and wires. The proposed transmission line would be constructed with modern hardware that eliminates such problems and therefore minimizes gap noise. Consequently, this source of EMI is not anticipated for the proposed line.

No state has limits for either RI or TVI. In the United States, electromagnetic interference from power transmission systems is governed by the Federal Communications Commission (FCC) Rules and Regulations presently in existence (FCC, 1988). A power transmission system falls into the FCC category of "incidental radiation device," which is defined as "a device that radiates radio frequency energy during the course of its operation although the device is not intentionally designed to generate radio frequency energy." Such a device "shall be operated so that the radio frequency energy that is emitted does not cause harmful interference. In the event that harmful interference is caused, the operator of the device shall promptly take steps to eliminate the harmful interference." For purposes of these regulations, harmful interference is defined as: "any emission, radiation or induction which endangers the functioning of a radio navigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radio communication service operating in accordance with this chapter" (FCC, 1988: Vol II, part 15. 47CFR, Ch. 1).

Electric power companies have been able to work quite well under the present FCC rule because harmful interference can generally be eliminated. It has been estimated that more than 95% of power-line sources that cause interference are due to gap-type discharges. These can be found and completely eliminated, when required to prevent interference (USDOE, 1980). Complaints related to corona-generated interference occur infrequently. This is especially true with the advent of cable television and satellite television, which are not subject to corona-generated interference. Mitigation of corona-generated interference with conventional radio and television receivers can be accomplished in several ways, such as use of a directional antenna or relocation of an existing antenna (USDOE, 1977; USDOE, 1980; Loftness et al., 1981).

8.2 Radio Interference (RI)

Radio reception in the AM broadcast band (535 to 1605 kilohertz (kHz)) is most often affected by corona-generated EMI. FM radio reception is rarely affected. Generally, only residences very near to transmission lines can be affected by RI. The IEEE Radio Noise Design Guide identifies an acceptable limit of fair-weather RI as expressed in decibels above 1 microvolt per meter (dBµV/m) of about 40 dBµV/m at 100 ft. (30 m) from the outside conductor (IEEE Committee Report, 1971). As a general rule, average levels during foul weather (when the conductors are wet) are 16 to 22 dBµV/m higher than average fair-weather levels.

8.3 Predicted RI Levels

Table 9 gives the predicted fair- and foul-weather RI levels (1000 kHz) at 100 ft. (30 m) from the outside conductor for the proposed 500-kV line in the four configurations. Median foul-weather levels would be about 17 dB higher than the fair-weather levels. The predicted L_{50} fair-weather level at the edge of the proposed right-of-way with no parallel lines is 45 dBµV/m for 540-kV line operation; at 100 ft. (30 m) from the outside conductor, the level is 36 dBµV/m. Predictions indicate that fair-weather RI will meet the IEEE 40 dBµV/m criterion at distances greater than about 100 ft. (30 m) from the outside conductor of the proposed line in all configurations. Predicted fair-weather L_{50} levels are comparable with those for the existing 345-kV line and lower than that from the existing 500-kV Hanford – John Day 500-kV line (45 dBµV/m at 100 ft. [30 m]).

8.4 Television Interference (TVI)

Corona-caused TVI occurs during foul weather and is generally of concern for transmission lines with voltages of 345 kV or above, and only for conventional receivers within about 600 ft. (183 m) of a line. As is the case for RI, gap sources on distribution and low-voltage transmission lines are the principal observed sources of TVI. The use of modern hardware and construction practices for the proposed line would minimize such sources.

8.5 Predicted TVI Levels

Table 10 shows TVI levels predicted at 100 ft. (30 m) from the outside conductor of the proposed line operating at 540 kV and from existing lines. At this distance, the foul-weather TVI level (75 megahertz (MHz)) predicted for the proposed line is 23 to 24 dBµV/m for all configurations. This is comparable with TVI levels from the existing 345-kV line and some other existing BPA 500-kV lines, and lower than that from the existing Hanford – John Day 500-kV line (33 dBµV/m at 100 ft. [30 m] from the outside conductor).

There is a potential for interference with television signals at locations very near the proposed line in fringe reception areas. However, several factors reduce the likelihood of occurrence. Corona-generated TVI occurs only in foul weather; consequently, signals would not be interfered with most of the time, which is characterized by fair weather. Because television antennas are directional, the impact of TVI is related to the location and orientation of the antenna relative to the transmission line. If the antenna were pointed away from the line, then TVI from the line would affect reception much less than if the antenna were pointed towards the line. Since the level of TVI falls off with distance, the potential for interference becomes minimal at distances greater than several hundred feet from the centerline. Where the proposed line parallels the existing 500-kV line with higher TVI levels, interference issues may have already been addressed and the potential for impacts would be less than where a new line with no parallel lines is built.

Other forms of TVI from transmission lines are signal reflection (ghosting) and signal blocking caused by the relative locations of the transmission structure and the receiving antenna with respect to the incoming television signal. Television systems that operate at higher frequencies, such as satellite receivers, are not affected by corona-generated TVI. Cable television systems are similarly unaffected.

Interference with television reception can be corrected by any of several approaches: improving the receiving antenna system; installing a remote antenna; installing an antenna for TV stations less vulnerable to interference; connecting to an existing cable system; or installing a translator (cf. USDOE, 1977). BPA has an active program to identify, investigate, and mitigate legitimate RI and TVI complaints. It is anticipated that any instances of TVI caused by the proposed line could be effectively mitigated.

8.6 Interference with Other Devices

Corona-generated interference can conceivably cause disruption on other communications bands such as the citizen's (CB) and mobile bands. However, mobile-radio communications are not susceptible to transmission-line interference because they are generally frequency modulated (FM). Similarly, cellular telephones operate at a frequency of about 900 MHz, which is above the frequency where corona-generated interference is prevalent. In the unlikely event that interference occurs with these or other communications, mitigation can be achieved with the same techniques used for television and AM radio interference.

8.7 Conclusion

Predicted EMI levels for the proposed 500-kV transmission line are comparable to, or lower, than those that already exist near 500-kV lines; no impacts of corona-generated interference on radio, television, or other reception are anticipated. Furthermore, if interference should occur, there are various methods for correcting it: BPA has a program to respond to legitimate complaints.

9.0 Other Corona Effects

Corona is visible as a bluish glow or as bluish plumes. On the proposed 500-kV line, corona levels would be very low, so that corona on the conductors would be observable only under the darkest conditions and only with the aid of binoculars, if at all. Without a period of adaptation for the eyes and without intentional looking for the corona, it would probably not be noticeable.

When corona is present, the air surrounding the conductors is ionized and many chemical reactions take place, producing small amounts of ozone and other oxidants. Ozone is approximately 90% of the oxidants, while the remaining 10% is composed principally of nitrogen oxides. The national primary ambient air quality standard for photochemical oxidants, of which ozone is the principal component, is a one-hour average not to exceed 235 micrograms/cubic meter) or 120 parts per billion. The maximum incremental ozone levels at ground level produced by corona activity on the proposed transmission line during foul weather would be much less than 1 part per billion. This level is insignificant when compared with natural levels and fluctuations in natural levels.

10.0 Summary

Electric and magnetic fields from the proposed transmission line have been characterized using well-known techniques accepted within the scientific and engineering community. The expected electric-field levels from the proposed line at minimum design clearance would be comparable to those from existing 500-kV lines in Oregon, Washington, and elsewhere. The expected magnetic-field levels from the proposed line would be comparable to, or less than, those from other 500-kV lines in Oregon, Washington, and elsewhere.

The peak electric field expected under the proposed line would be less than 9.0 kV/m; the maximum value at the edge of the right-of-way would be about 2.8 kV/m. Clearances at road crossings would be increased to reduce the peak electric-field value to 4.4 kV/m.

Under maximum current conditions, the maximum magnetic fields under the proposed line would be 311 mG; at the edge of the right-of-way of the proposed line the maximum magnetic field would be 89 mG.

The electric fields from the proposed line would meet regulatory limits for public exposure in Oregon, but could exceed the regulatory limits or guidelines for peak fields established in some other states and by ICNIRP. Washington does not have a limit for electric fields from transmission lines. The magnetic fields from the proposed line would be within the regulatory limits of the two states that have established them and within guidelines for public exposure established by ICNIRP. Oregon and Washington do not have any magnetic-field regulatory limits or guidelines.

Short-term effects from transmission-line fields are well understood and can be mitigated. Nuisance shocks arising from electric-field induced currents and voltages could be perceivable on the right-of-way of the proposed line. It is common practice to ground permanent conducting objects during and after construction to mitigate against such occurrences.

Corona-generated audible noise from the line would be perceivable during foul weather in areas where there are no immediately adjacent parallel lines. In sections with parallel lines the increase in audible noise during foul weather caused by the proposed line would be barely perceptible. The levels would be comparable to those near existing 500-kV transmission lines in Oregon and Washington, would be in compliance with noise regulations in Oregon and Washington, and would be below levels specified in EPA guidelines.

Corona-generated electromagnetic interference from the proposed line would be comparable to or less than that from existing 500-kV lines in Washington and Oregon. Radio interference levels would be below limits identified as acceptable. Television interference, a foul-weather phenomenon, is anticipated to be comparable to or less than that from existing 500-kV lines in Oregon and Washington; if legitimate complaints arise, BPA has a mitigation program.

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Table 1: Possible configurations for McNary – John Day 500-kV corridor.

Configuration	Description of other lines in corridor with McNary – John Day 500-kV line	Miles
1	McNary – Horse Heaven – Harvalum 230-kV and McNary – Ross 345-kV lines[1]	73.0
2	Horse Heaven – Harvalum 230-kV, McNary – Ross 345-kV, and Ashe – Marion No. 1/ Ashe – Slat No. 1 double-circuit 500-kV	4.1
3	Proposed McNary – John Day 500-kV line only	3.0
4	Horse Heaven – Harvalum 230-kV, McNary – Ross 345-kV, and Hanford – John Day 500-kV lines (125-ft. spacing)	—[2]
4A	Horse Heaven – Harvalum 230-kV, McNary – Ross 345-kV, and re-located Hanford – John Day 500-kV lines (proposed line located on existing Hanford – John Day towers)	—[2]
4B	Horse Heaven – Harvalum 230-kV, McNary – Ross 345-kV, and Hanford – John Day 500-kV lines (275-ft. spacing)	—[2]

[1] Four different electrical phasing options are present. Only maximum field results are presented.
[2] Length of individual configurations depends on engineering design. Total length of section parallel to Hanford –John Day 500-kV line is 6.7 miles.

Table 2: Physical and electrical characteristics of configurations in the McNary – John Day 500-kV transmission-line corridor. (4 pages)

	Proposed	**Existing Lines in Corridor**	
Configuration	**3**	**1**	
Line Description	**McNary – John Day 500-kV Only**	**McNary – Horse Heaven – Harvalum 230-kV**	**McNary – Ross 345-kV**
Voltage, kV Maximum/Average[1]	550/540	242/237	362/355
Peak current, A Existing/Proposed	1758	1107/985	516/604
Electric phasing (south-north)	CBA	CBA[2]	ACB[2]
Clearance, ft. Minimum/Average[1]	35/45	26.5/36.5	34/44
Centerline distance-direction from McNary – John Day 500-kV Line, ft.	—[3]	250 South	125 South
Centerline distance to edge of ROW, ft.	72.5 – 187.5	62.5	62.5
Tower configuration	Delta	Flat	Flat
Phase spacing, ft.	48H, 34.5V	26.3H	32H
Conductor: #/diameter, in.; spacing, in.	3/1.300; 17.04	1/1.382	1/1.602

1 Average voltage and average clearance used for corona calculations.
2 Most prevalent phasing scheme; three other phasing schemes also present in corridor.
3 Existing lines are 625 feet south of proposed line and affect audible noise but not electric or magnetic fields near proposed line.

Table 2, continued

	Existing Lines in Corridor			
Configuration	**2**			
Line Description	**Horse Heaven – Harvalum 230-kV**	**McNary – Ross 345-kV**	**Ashe – Marion No. 1/ Ashe – Slatt No. 1 500-kV Double Circuit**	
Voltage, kV Maximum/Average[1]	242/237	362/355	550/540	
Peak current, A Existing/Proposed	817/805	516/604	1239/1332	1760/1802
Electric phasing (south-north)	CBA	ACB	A A B C C B	
Clearance, ft. Minimum/Average[1]	26.5/36.5	34/44	35/45	
Centerline distance-direction from McNary – John Day 500-kV Line, ft.	435 South	310 South	200 South	
Centerline distance to edge of ROW, ft.	62.5	—	100	
Tower configuration	Flat	Flat	Vertical, Double-circuit	
Phase spacing, ft.	26.3H	32H	30H, 50H, 30H, 31V	
Conductor: #/diameter, in.; spacing, in.	1/1.382	1/1.602	3/1.602; 17.04	

[1] Average voltage and average clearance used for corona calculations.

Table 2, continued

Configuration	Existing Lines in Corridor 4, 4B		
Line Description	**Horse Heaven – Harvalum 230-kV**	**McNary – Ross 345-kV**	**Hanford – John Day 500-kV**
Voltage, kV Maximum/Average[1]	242/237	362/355	550/540
Peak current, A Existing/Proposed	817/805	516/604	1797/1842
Electric phasing (south-north)	BAC	BAC	CBA
Clearance, ft. Minimum/Average[1]	26.5/36.5	34/44	33/43
Centerline distance-direction from McNary – John Day 500-kV Line, ft.	125 North (4) 275 North (4B)	250 North (4) 400 North (4B)	375 North (4) 525 North (4B)
Centerline distance to edge of ROW, ft.	62.5	—	220
Tower configuration	Flat	Flat	Delta
Phase spacing, ft.	26.3H	32H	40H, 27.5V
Conductor: #/diameter, in.; spacing, in.	1/1.382	1/1.602	2/1.602; 18.0

[1] Average voltage and average clearance used for corona calculations.

Table 2, continued

Configuration	Existing Lines in Corridor 4A		
Line Description	**Horse Heaven – Harvalum 230-kV**	**McNary – Ross 345-kV**	**Hanford – John Day 500-kV**[4]
Voltage, kV Maximum/Average[1]	242/237	362/355	550/540
Peak current, A Existing/Proposed	817/805	516/604	1797/1842
Electric phasing (south-north)	BAC	BAC	CBA
Clearance, ft. Minimum/Average[1]	26.5/36.5	34/44	33/43
Centerline distance-direction from McNary – John Day 500-kV Line, ft.	250 South	125 South	0 North[4]
Centerline distance to edge of ROW, ft.	62.5	—	220 (existing) 75 (proposed)
Tower configuration	Flat	Flat	Delta
Phase spacing, ft.	26.3H	32H	40H, 27.5V
Conductor: #/diameter, in.; spacing, in.	1/1.382	1/1.602	2/1.602; 18.0

[1] Average voltage and average clearance used for corona calculations.

[4] Data is for existing configuration. Proposed line would be located on the existing towers and the Hanford – John Day 500-kV line would be re-located 200 feet north of its existing location on new towers with 3/1.300-in. conductors (Figure 1e).

Table 3: Calculated peak and edge-of-right-of-way electric fields for the proposed McNary – John Day 500-kV line operated at maximum voltage by configuration. Configurations are described in Tables 1 and 2 and shown in Figure 1.

a) Peak electric field on right-of-way, kV/m

Location	Under Proposed Line		In Remainder of Proposed Corridor		In Existing Corridor	
Line Clearance	Minimum	Average	Minimum	Average	Minimum	Average
Configuration 1	8.9	6.0	4.8	3.4	4.7	3.3
Configuration 2	8.9	6.0	8.8	6.4	8.8	6.3
Configuration 3	9.0	6.0	—	—	—	—
Configuration 4	8.8	5.9	8.9	6.0	8.9	6.0
Configuration 4A	8.9	6.0	8.8	5.9	8.9	6.0
Configuration 4B	8.8	5.9	8.9	6.0	8.9	6.0

b) Electric field at edge of proposed right-of-way, kV/m

Location	Adjacent to Proposed Line[1]		Adjacent to Existing Line in Proposed Corridor		In Existing Corridor[1]	
Line Clearance	Minimum	Average	Minimum	Average	Minimum	Average
Configuration 1	0.3	0.3	1.4	1.3	0.03, 1.4	0.04, 1.3
Configuration 2	2.8	2.8	1.2	1.1	0.3, 1.2	0.3, 1.1
Configuration 3	2.5, 0.4	2.4, 0.4	—	—	—	—
Configuration 4	2.5	2.5	0.2	0.2	0.1, 0.2	0.1, 0.2
Configuration 4A	2.5	2.5	1.5	1.4	0.1, 1.5	0.1,1.4
Configuration 4B	2.5	2.5	0.2	0.2	0.1, 0.2	0.1, 0.2

[1] Electric field at edge of right-of-way adjacent to proposed line is given first, except for Configuration 3, where levels at 75 and 175 ft. from centerline are given.

Table 4: Calculated peak and edge-of-right-of-way magnetic fields for the proposed McNary – John Day 500-kV line operated at maximum current by configuration. Configurations are described in Tables 1 and 2 and shown in Figure 1.

a) Peak magnetic field on right-of-way, mG

Location	Under Proposed Line		In Remainder of Proposed Corridor		In Existing Corridor	
Line Clearance	Minimum	Average	Minimum	Average	Minimum	Average
Configuration 1	296	203	261	166	298	192
Configuration 2	309	216	241	178	225	162
Configuration 3	303	207	—	—	—	—
Configuration 4	301	207	333	218	327	215
Configuration 4A	311	202	302	205	327	215
Configuration 4B	296	203	335	219	327	215

b) Magnetic field at edge of proposed right-of-way, mG

Location	Adjacent to Proposed Line[1]		Adjacent to Existing Line in Proposed Corridor		In Existing Corridor[1]	
Line Clearance	Minimum	Average	Minimum	Average	Minimum	Average
Configuration 1	17	17	78	65	3, 84	3, 71
Configuration 2	89	79	58	47	12, 58	12, 48
Configuration 3	82, 16	71, 16	—	—	—	—
Configuration 4	77	67	10	10	8, 9	7, 9
Configuration 4A	89	77	69	60	69, 6	59, 6
Configuration 4B	80	70	10	10	3, 9	3, 9

[1] Magnetic field at edge of right-of-way adjacent to proposed line is given first, except for Configuration 3,where levels at 75 and 175 ft. from centerline are given.

Table 5: States with transmission-line field limits.

STATE AGENCY	WITHIN RIGHT-OF-WAY	AT EDGE OF RIGHT-OF-WAY	COMMENTS
a. 60-Hz ELECTRIC-FIELD LIMIT, kV/m			
Florida Department of Environmental Regulation	8 (230 kV) 10 (500 kV)	2	Codified regulation, adopted after a public rulemaking hearing in 1989.
Minnesota Environmental Quality Board	8	—	12-kV/m limit on the high-voltage direct-current (HVDC) nominal electric field.
Montana Board of Natural Resources and Conservation	7[1]	1[2]	Codified regulation, adopted after a public rulemaking hearing in 1984.
New Jersey Department of Environmental Protection	—	3	Used only as a guideline for evaluating complaints.
New York State Public Service Commission	11.8 (7,11)[1]	1.6	Explicitly implemented in terms of a specified right-of-way width.
Oregon Facility Siting Council	9	—	Codified regulation, adopted after a public rulemaking hearing in 1980.
b. 60-Hz MAGNETIC-FIELD LIMIT, mG			
Florida Department of Environmental Regulation	—	150 (230 kV) 200 (500 kV)	Codified regulations, adopted after a public rulemaking hearing in 1989.
New York State Public Service Commission	—	200	Adopted August 29, 1990.

[1] At road crossings
[2] Landowner may waive limit

Sources: TDHS Report, 1989; TDHS Report, 1990

Table 6: Common noise levels.

Sound Level, dBA	Noise Source or Effect
128	Threshold of pain
108	Rock-and-roll band
80	Truck at 50 ft.
70	Gas lawnmower at 100 ft.
60	Normal conversation indoors
50	Moderate rainfall on foliage
47	Edge of proposed 500-kV right-of-way during rain
40	Refrigerator
25	Bedroom at night
0	Hearing threshold

Adapted from: USDOE, 1996.

Table 7: Typical sound attenuation (in decibels) provided by buildings.

	Windows opened	Windows closed
Warm climate	12	24
Cold climate	17	24

Source: EPA, 1978.

Table 8: Predicted foul-weather audible noise (AN) levels at edge of proposed right-of-way (ROW) for the McNary – John Day 500-kV line by configuration. AN levels expressed in decibels on the A-weighted scale (dBA). L_{50} and L_5 denote the levels exceeded 50 and 5 percent of the time, respectively. Configurations are described in Tables 1 and 2 and shown in Figure 1.

Configuration[1]	Foul-weather AN			
	Proposed Corridor[1]		Existing Corridor[1]	
	L_{50}, dBA	L_5, dBA	L_{50}, dBA	L_5, dBA
1	49, 50	52, 54	46, 49	50, 53
2	51, 50	54, 54	47, 50	51, 53
3	49, 46	52, 49	43, 41	46, 45
4	53, 54	56, 57	51, 54	55, 57
4A	54, 53	57, 57	53,53	56, 57
4B	52, 54	55, 57	50, 54	53, 57

[1] AN level at edge of right-of-way adjacent to proposed line is given first, except for Configuration 3, where levels at 75 and 175 ft. from centerline are given.

Table 9: Predicted fair-weather radio interference (RI) levels at 100 feet (30.5 m) from the outside conductor of the proposed McNary – John Day 500-kV line by configuration. RI levels given in decibels above 1 microvolt/meter (dBµV/m) at 1.0 MHz. L_{50} denotes level exceeded 50 percent of the time. Configurations are described in Tables 1 and 2 and shown in Figure 1.

Configuration	Fair-weather RI	
	Proposed Corridor [1]	Existing Corridor[1]
	L_{50}, dBµV/m	L_{50}, dBµV/m
1	38, 31	39, 30
2	38, 31	38, 31
3	37	—
4	37, 45	33, 45
4A	37, 33	45, 33
4B	37, 45	33, 45

[1] RI level at 100 ft. from outside conductor of proposed line given first.

Table 10: Predicted maximum foul-weather television interference (TVI) levels at 100 feet (30.5 m) from the outside conductor of the proposed McNary – John Day 500-kV line by configuration. TVI levels given in decibels above 1 microvolt/meter (dBμV/m) at 75 MHz. Configurations are described in detail in Tables 1 and 2 and shown in Figure 1.

	Foul-weather TVI	
	Proposed Corridor[1]	Existing Corridor[1]
Configuration	**Maximum (foul), dBμV/m**	**Maximum (foul), dBμV/m**
1	23, 14	26, 14
2	23, 14	21, 14
3	23	—
4	23, 33	14, 33
4A	23, 14	33, 14
4B	23, 33	14, 33

[1] TVI level at 100 ft. from outside conductor of proposed line is given first.

Figure 1: Configurations for the proposed McNary – John Day 500-kV line: a) Proposed line with parallel 230-kV and 345-kV lines (Configuration 1); b) Proposed line with parallel 230-kV, 345-kV, and double-circuit 500-kV lines (Configuration 2); c) Proposed line with no parallel lines (Configuration 3); d) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configurations 4 and 4B); and e) Proposed line on existing Hanford – John Day 500-kV line towers with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4A). (5 pages)

a) Proposed line with parallel 230-kV and 345-kV lines (Configuration 1) (not to scale)

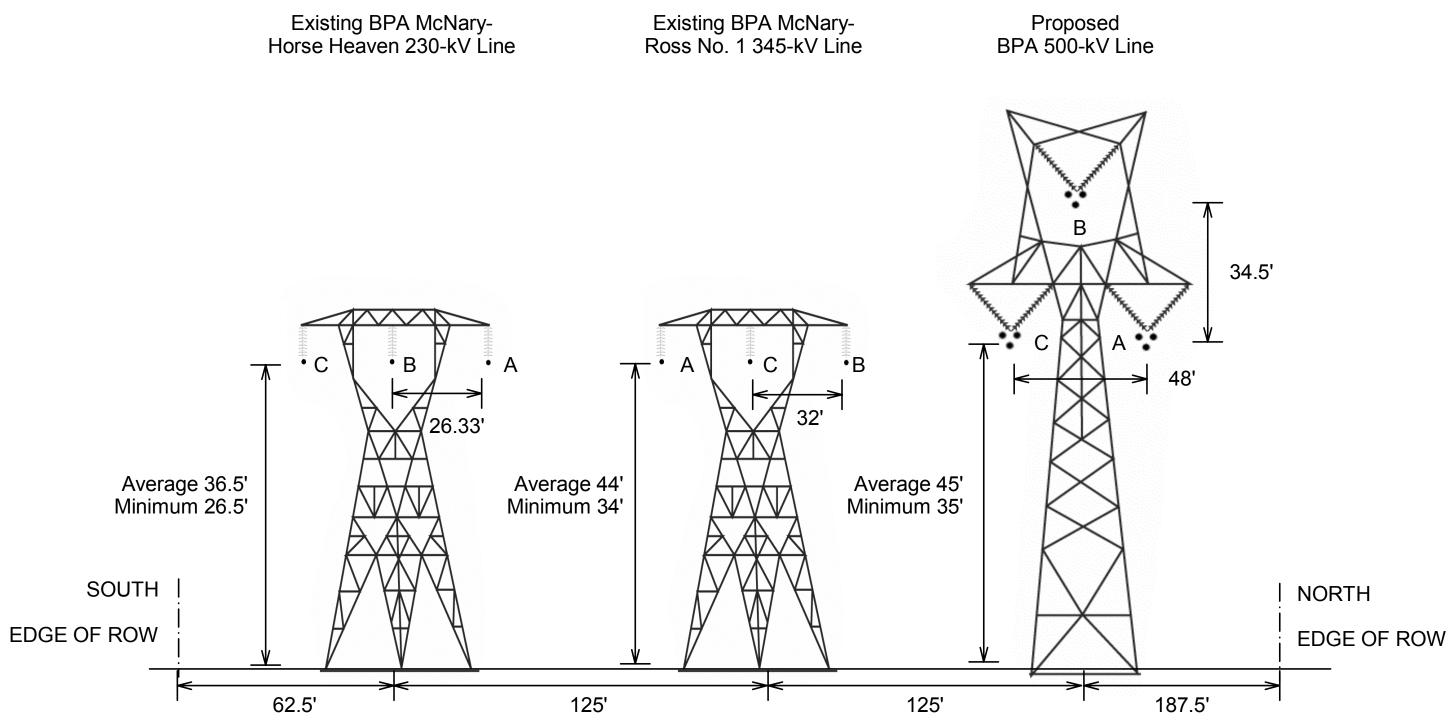


Figure 1, continued

b) Proposed line with parallel 230-kV, 345-kV, and double-circuit 500-kV lines (Configuration 2) (not to scale)

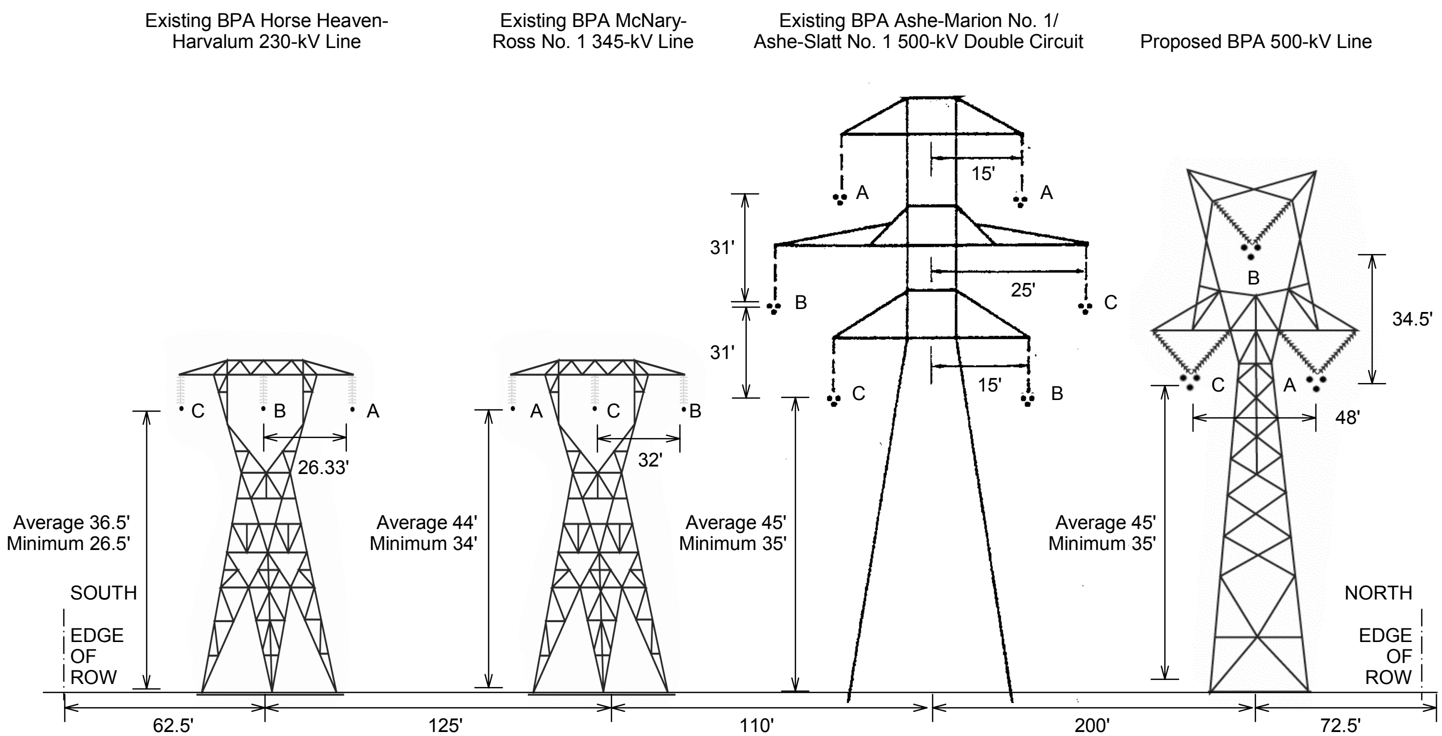


Figure 1, continued

c) Proposed line with no parallel lines within 600 feet (Configuration 3) (not to scale)

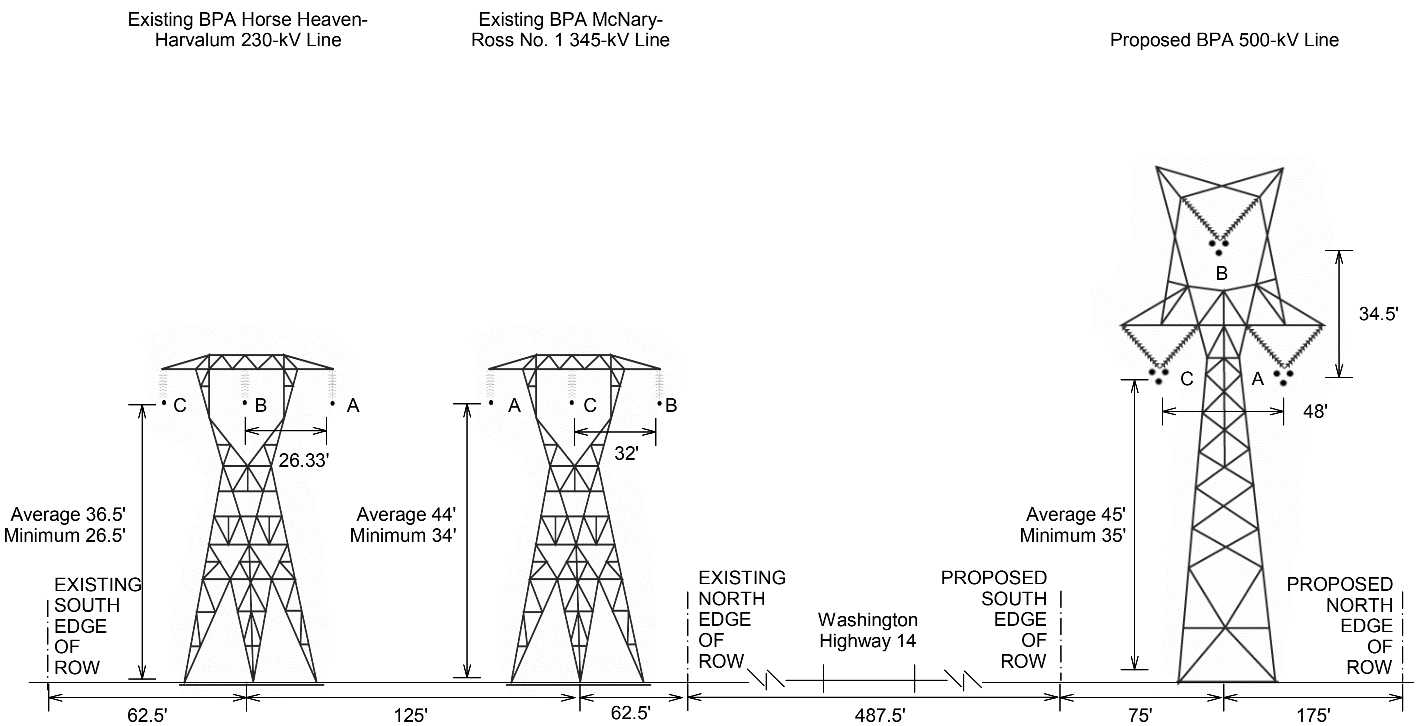


Figure 1, continued

d) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configurations 4 and 4B) (not to scale)

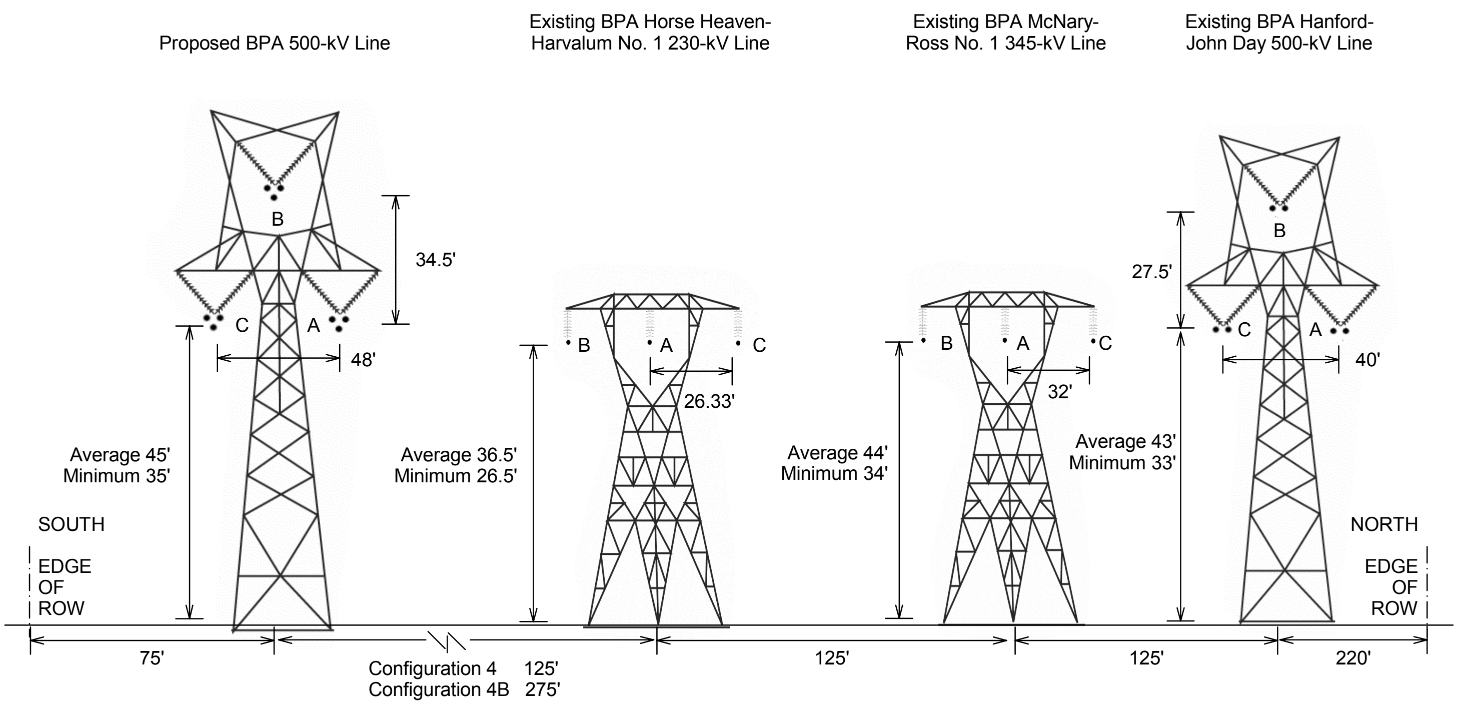


Figure 1, continued

e) Proposed line on existing Hanford – John Day 500-kV towers with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4A) (not to scale)

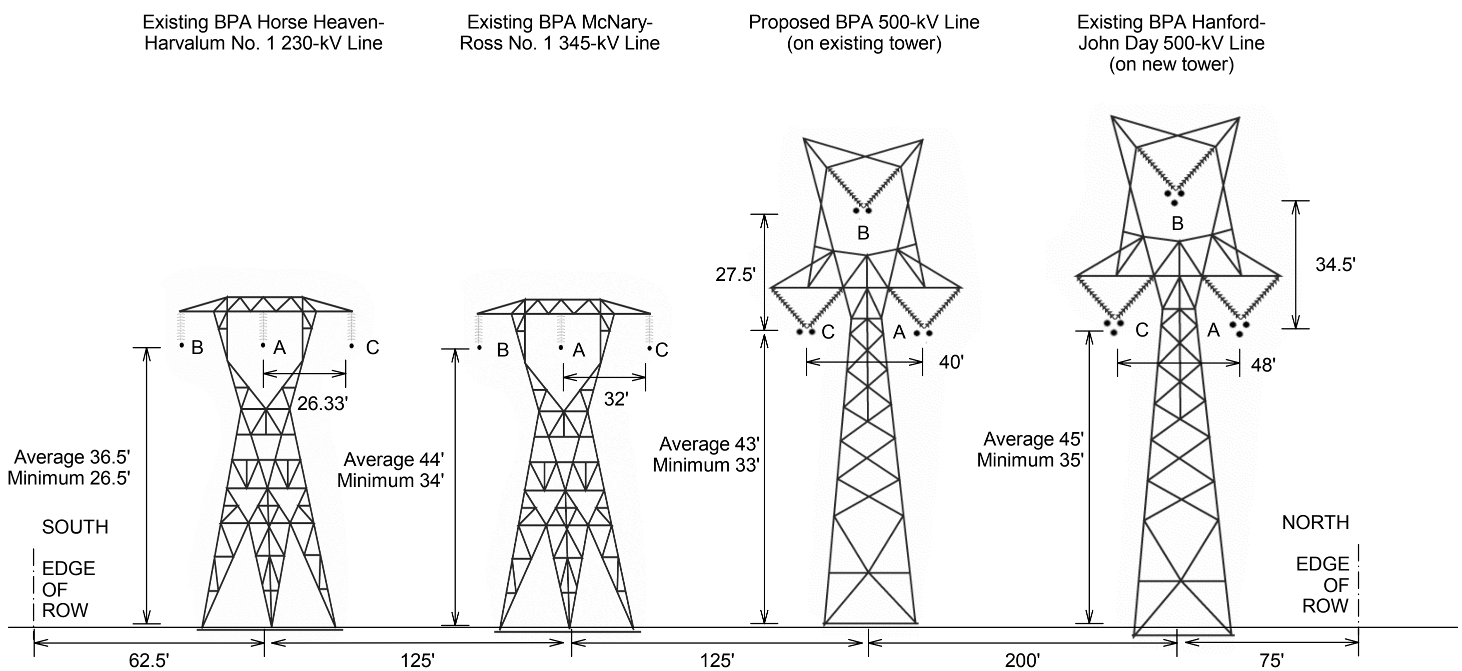


Figure 2: Electric-field profiles for configurations of the proposed McNary – John Day 500-kV line under maximum voltage conditions: a) Proposed line with parallel 230-kV and 345-kV lines (Configuration 1); b) Proposed line with parallel 230-kV, 345-kV, and double-circuit 500-kV lines (Configuration 2); c) Proposed line with no parallel lines within 600 feet (Configuration 3); d) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configurations 4); e) Proposed line on existing towers with parallel 230-kV, 345-kV, and 500-kV lines (Configurations 4A); and f) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4B). (4 pages) Configurations are described in Tables 1 and 2 and shown in Figure 1.

a) Proposed line with parallel 230-kV and 345-kV lines (Configuration 1)

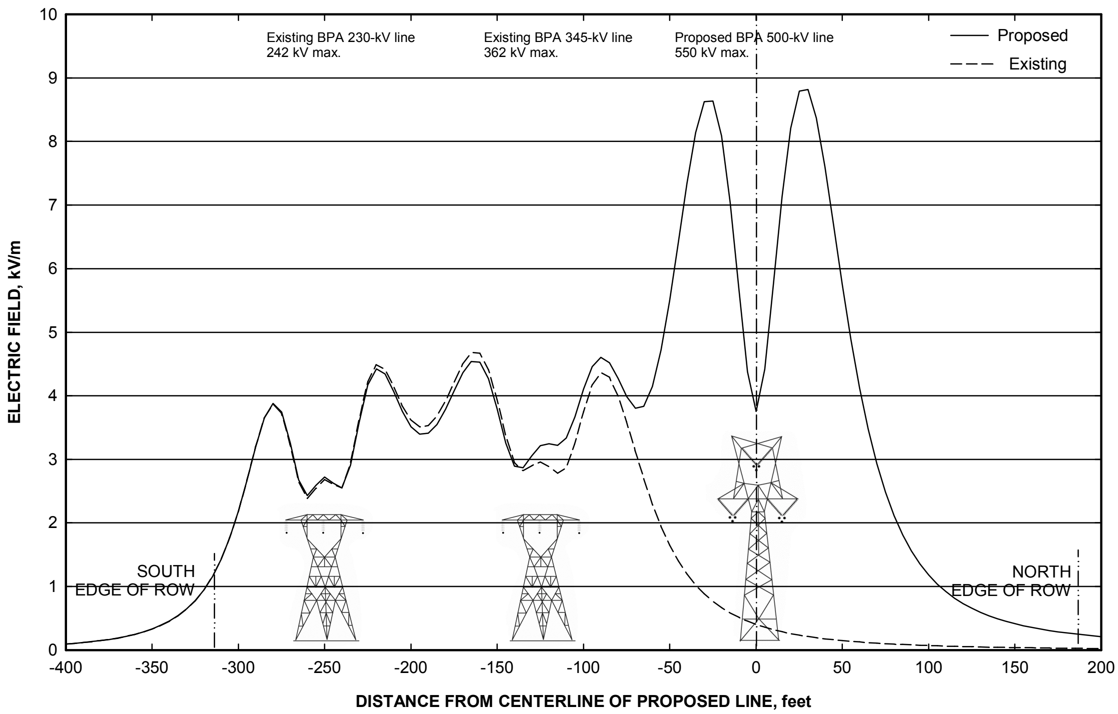
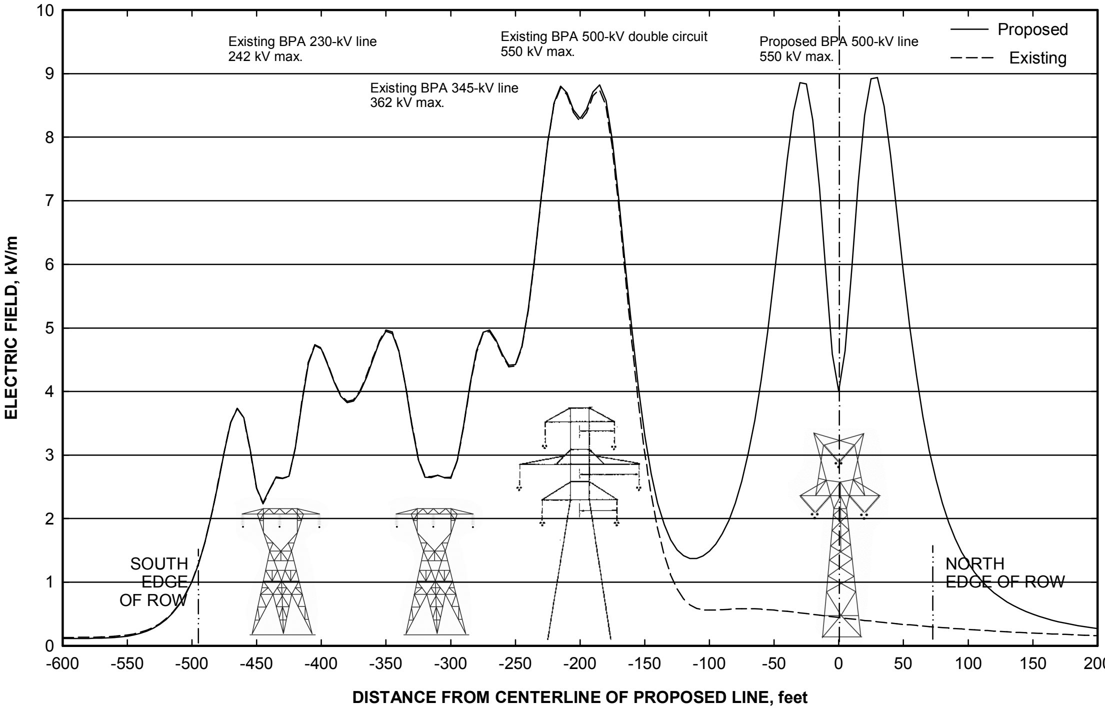


Figure 2, continued

b) Proposed line with parallel 230-kV, 345-kV, and double-circuit 500-kV lines (Configuration 2)



c) Proposed line with no parallel lines within 600 feet (Configuration 3)

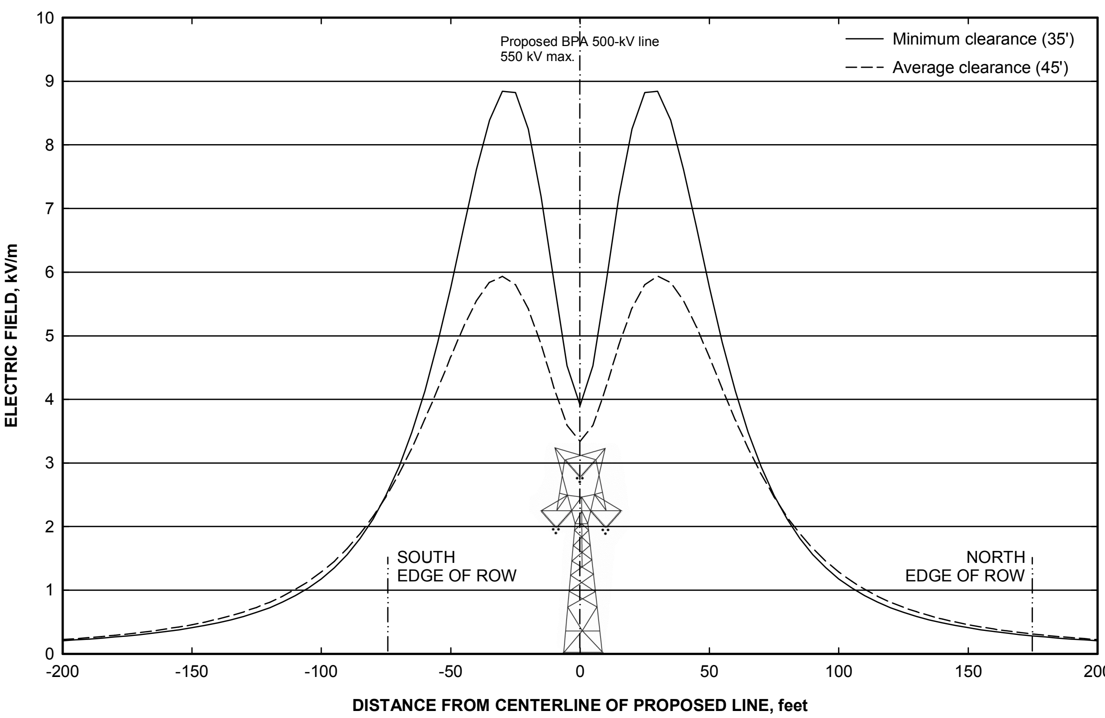
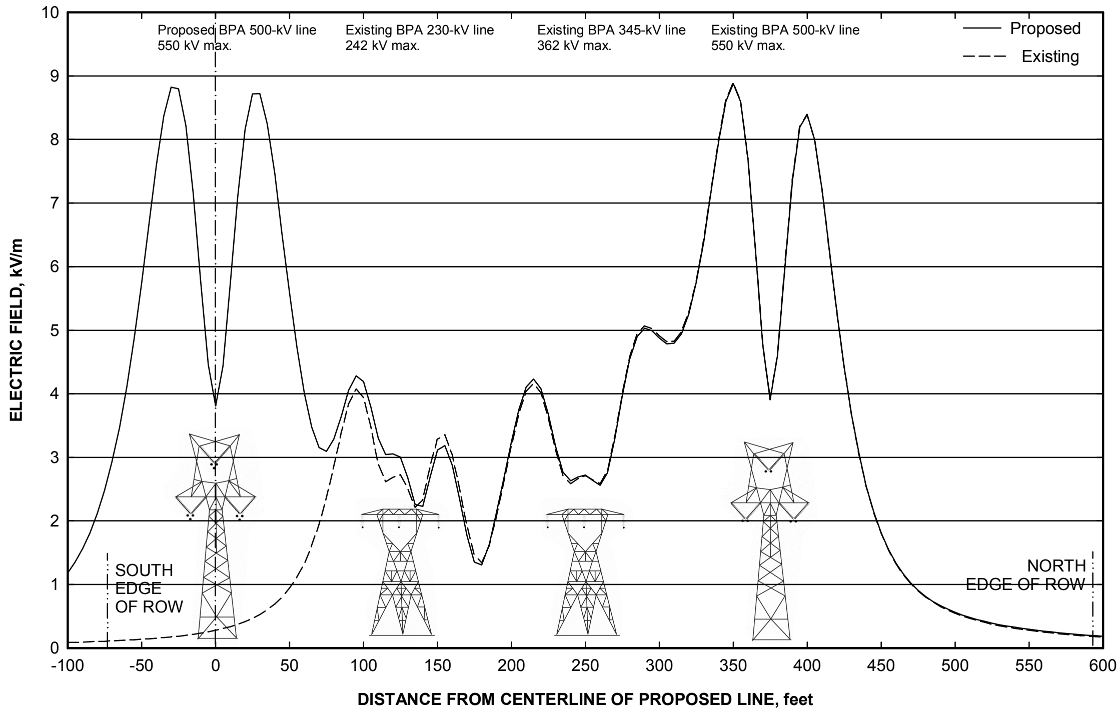


Figure 2, continued

d) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4, 125-ft. spacing)



e) Proposed line on existing towers with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4A)

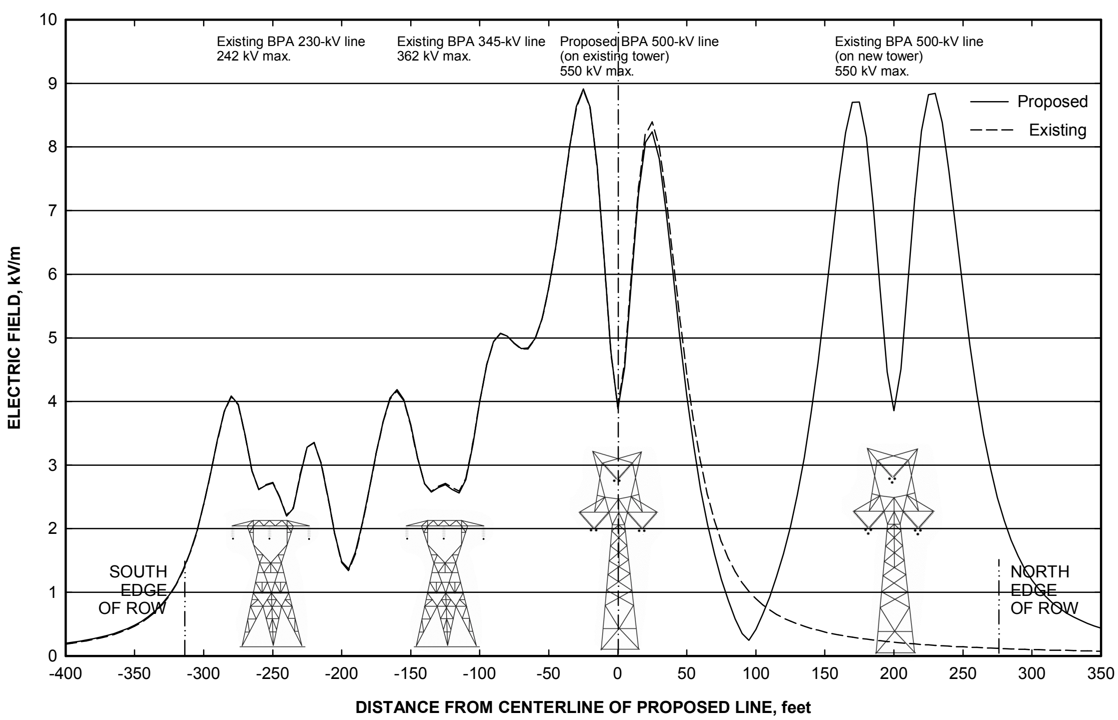


Figure 2, continued

f) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4B, 275-ft. spacing)

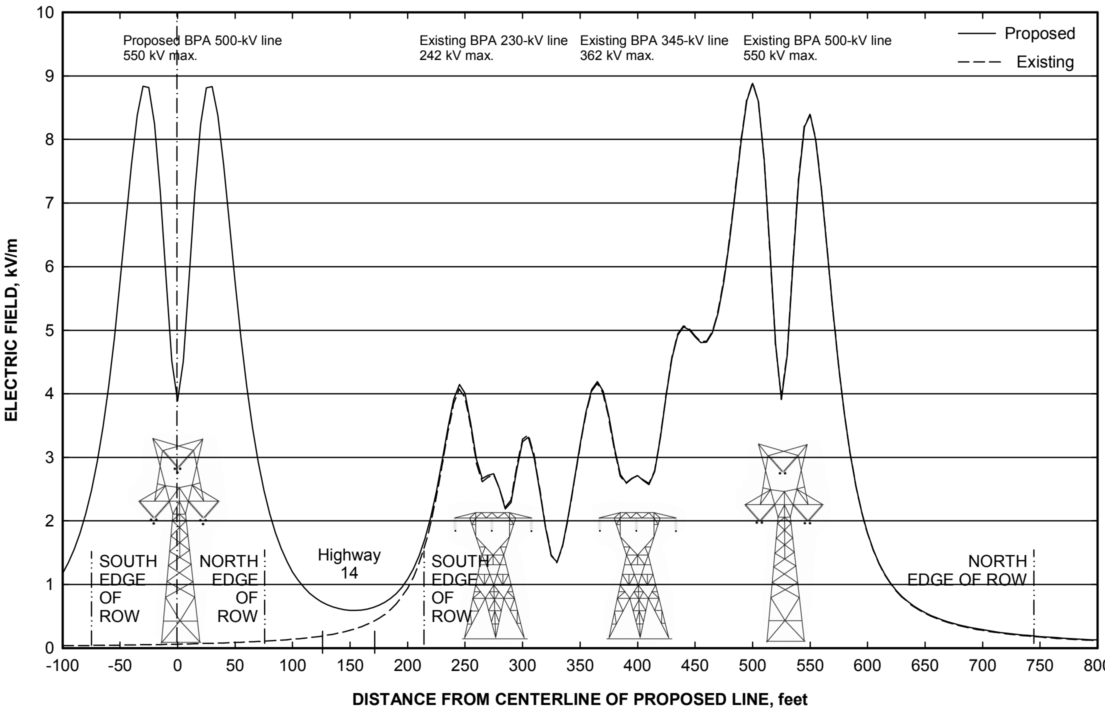


Figure 3: Magnetic-field profiles for configurations of the proposed McNary – John Day 500-kV line under maximum current conditions: a) Proposed line with parallel 230-kV and 345-kV lines (Configuration 1); b) Proposed line with parallel 230-kV, 345-kV, and double-circuit 500-kV lines (Configuration 2); c) Proposed line with no parallel lines (Configuration 3); and d) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4); e) Proposed line on existing towers with parallel 230-kV, 345-kV, and 500-kV lines (Configurations 4A); and f) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4B). (4 pages) Configurations are described in Tables 1 and 2 and shown in Figure 1.

a) Proposed line with parallel 230-kV and 345-kV lines (Configuration 1)

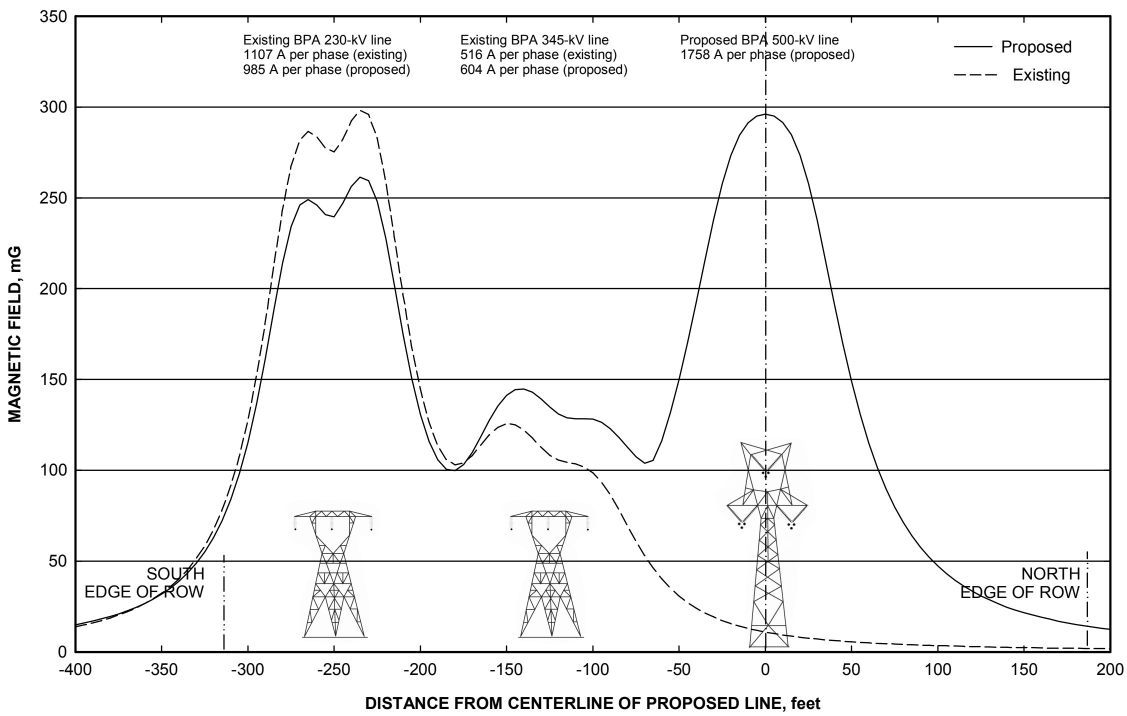
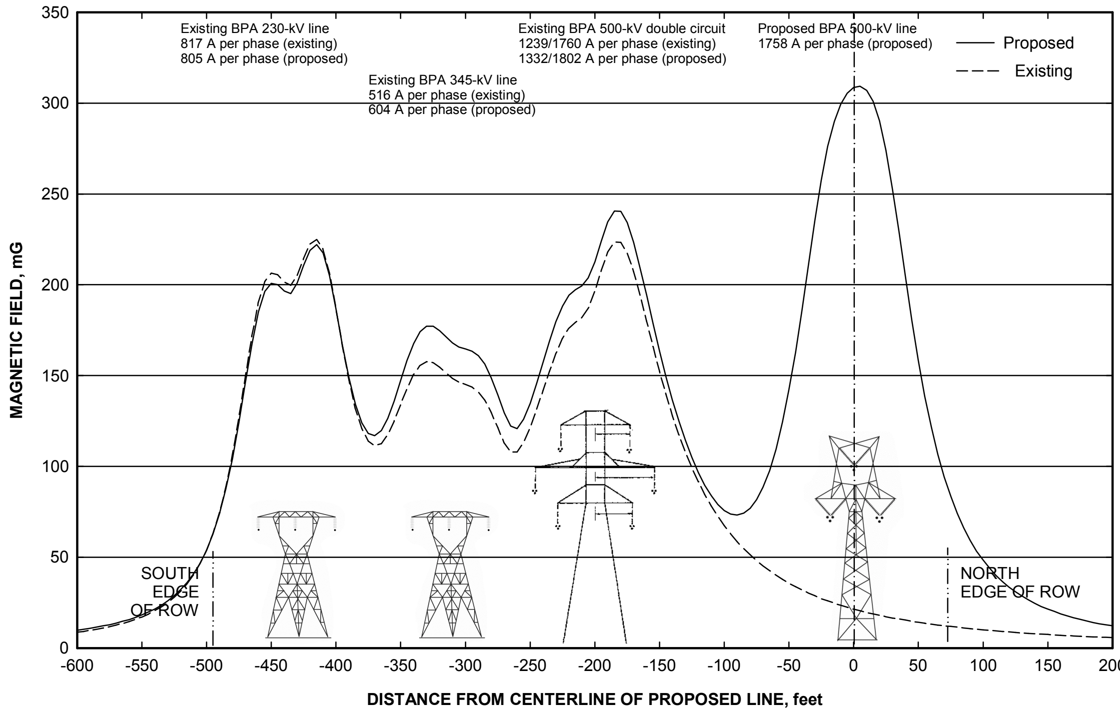


Figure 3, continued

b) Proposed line with parallel 230-kV, 345-kV, and double-circuit 500-kV lines (Configuration 2)



c) Proposed line with no parallel lines within 600 feet (Configuration 3)

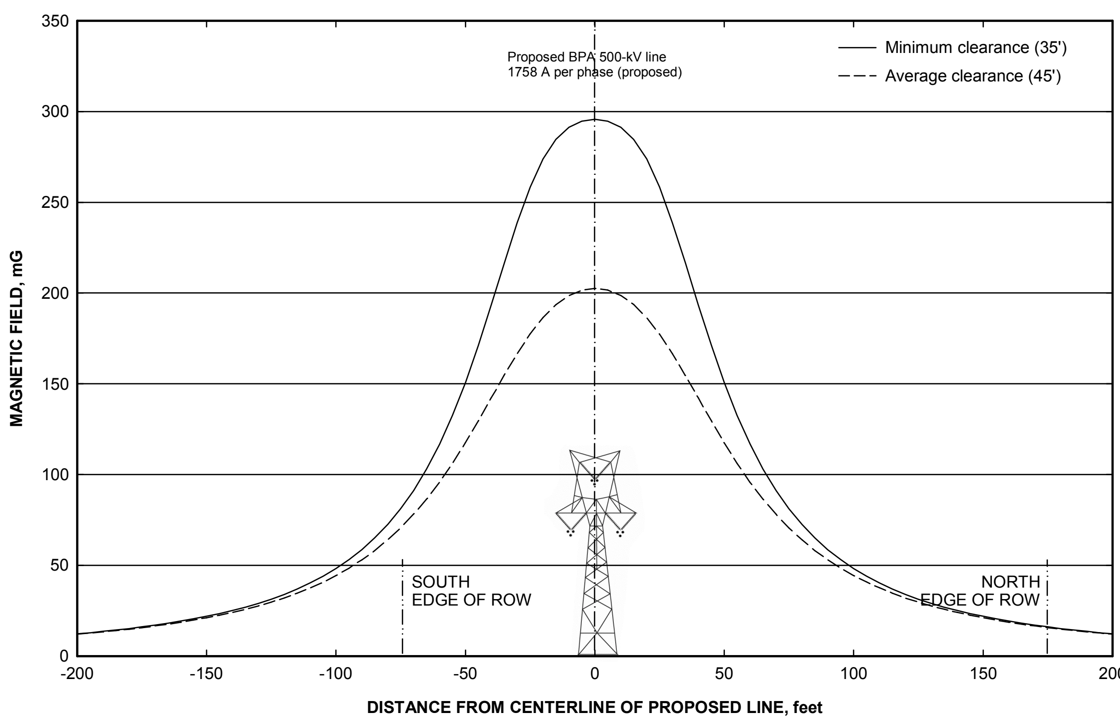
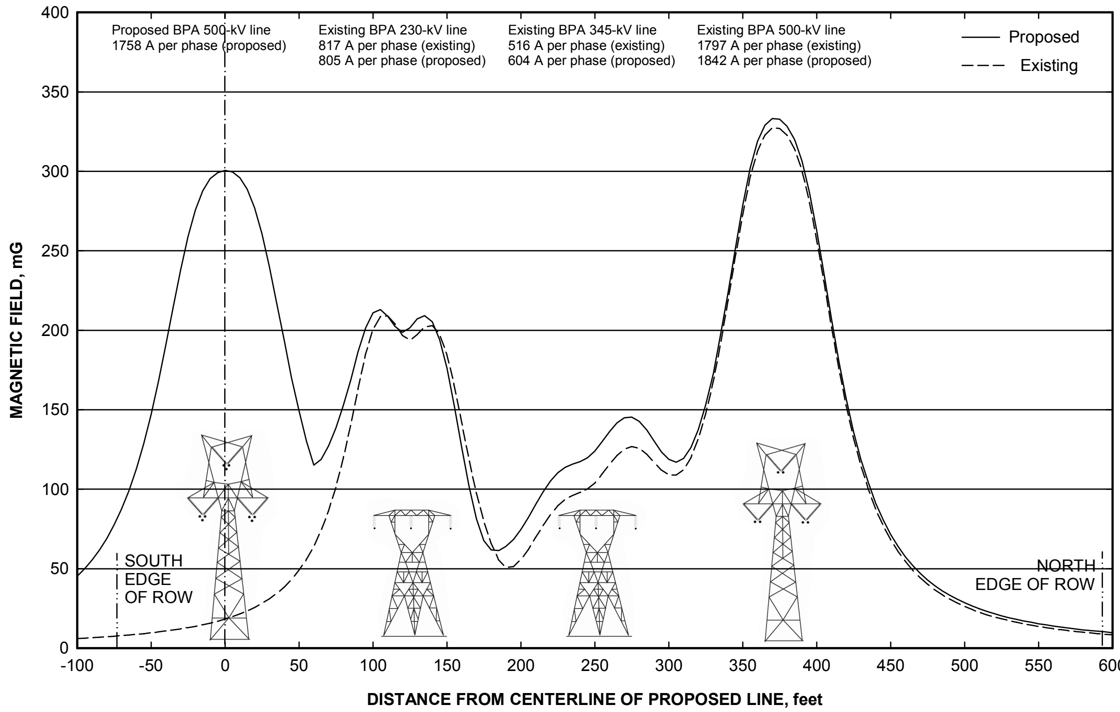


Figure 3, continued

d) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4, 125-ft. spacing)



e) Proposed line on existing towers with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4A)

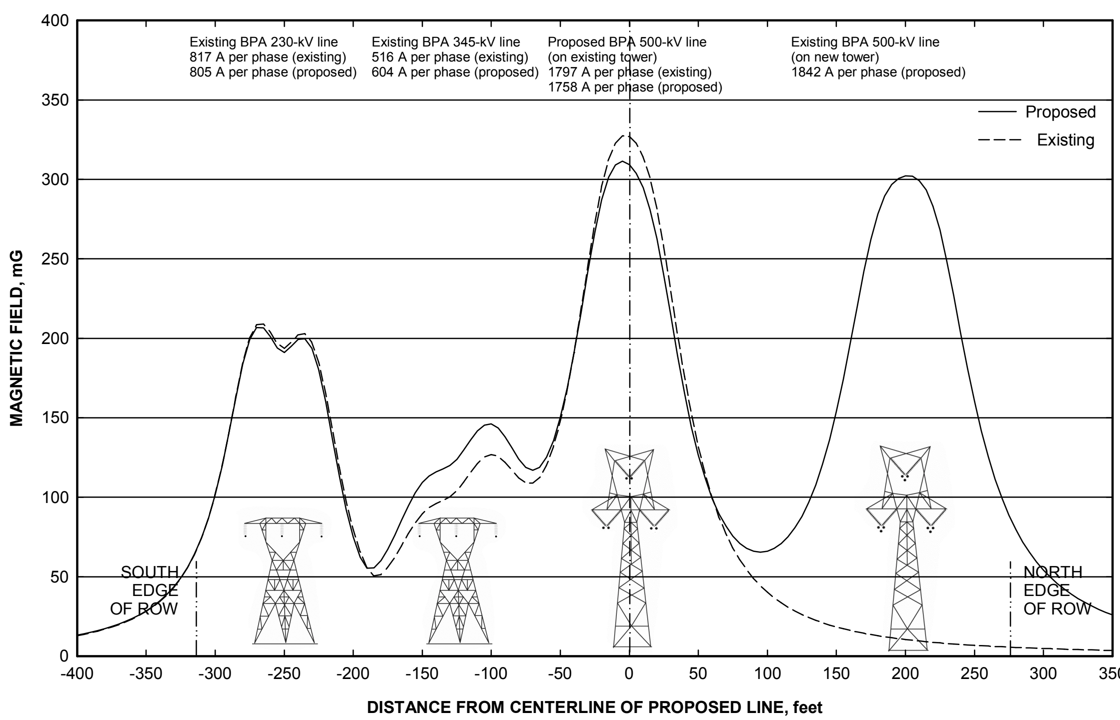


Figure 3, continued

f) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4B, 275-ft. spacing)

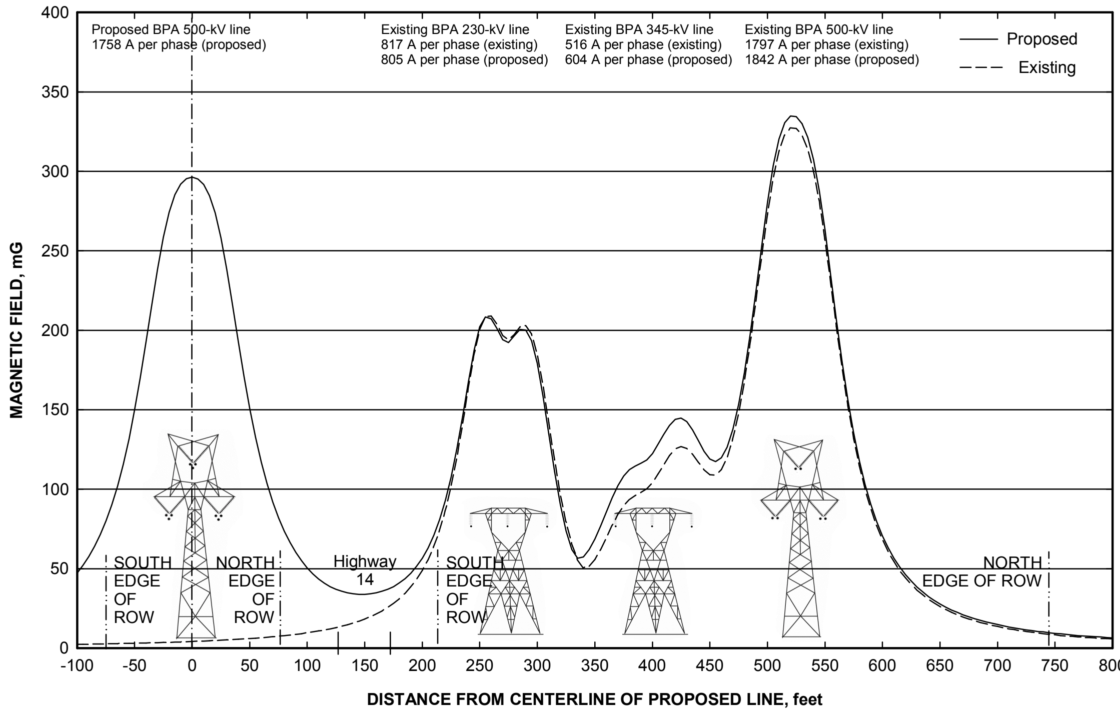


Figure 4: Predicted foul-weather L_{50} audible noise levels from configurations of proposed McNary – John Day 500-kV line: a) Proposed line with parallel 230-kV and 345-kV lines (Configuration 1); b) Proposed line with parallel 230-kV, 345-kV, and double-circuit 500-kV lines (Configuration 2); c) Proposed line with no parallel lines (Configuration 3); and d) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4); e) Proposed line on existing towers with parallel 230-kV, 345-kV, and 500-kV lines (Configurations 4A); and f) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4B). (4 pages) Configurations are described in Tables 1 and 2 and shown in Figure 1.

a) Proposed line with parallel 230-kV and 345-kV lines (Configuration 1)

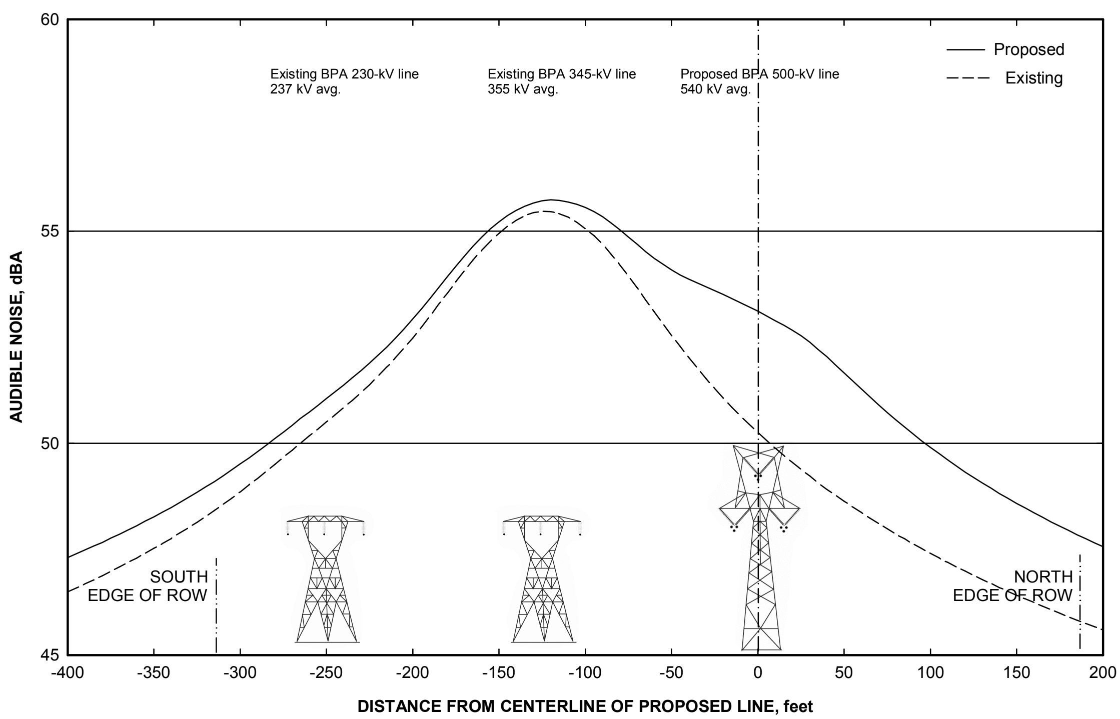
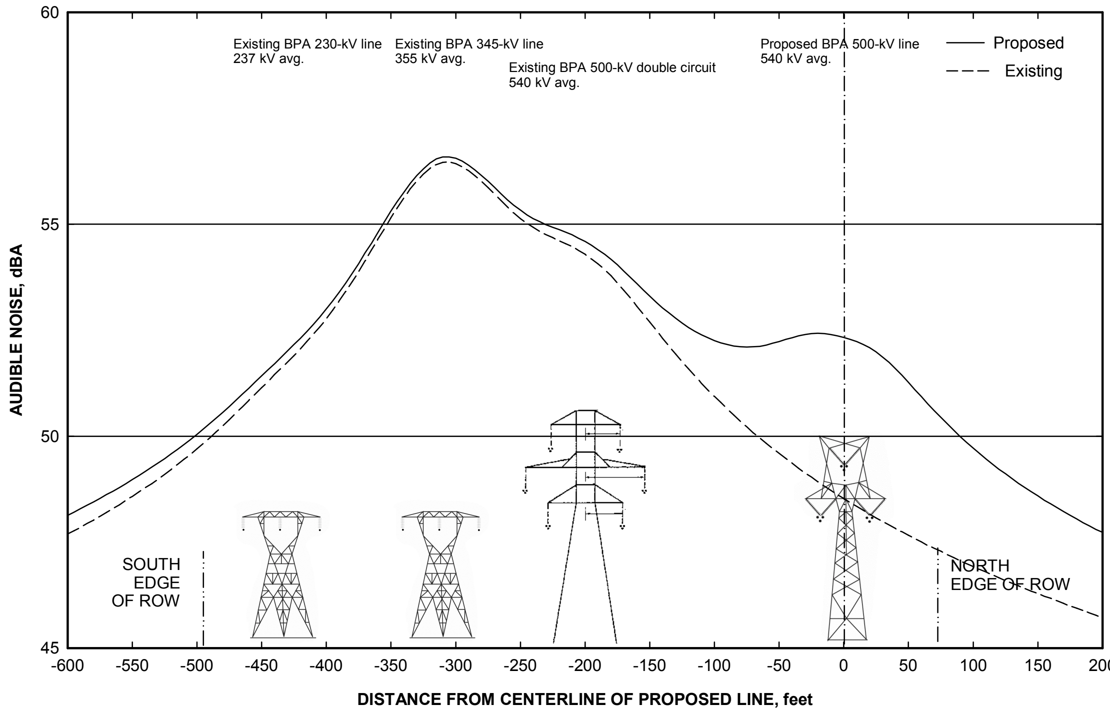


Figure 4, continued

b) Proposed line with parallel 230-kV, 345-kV, and double-circuit 500-kV lines (Configuration 2)



c) Proposed line with no parallel lines within 600 feet (Configuration 3)

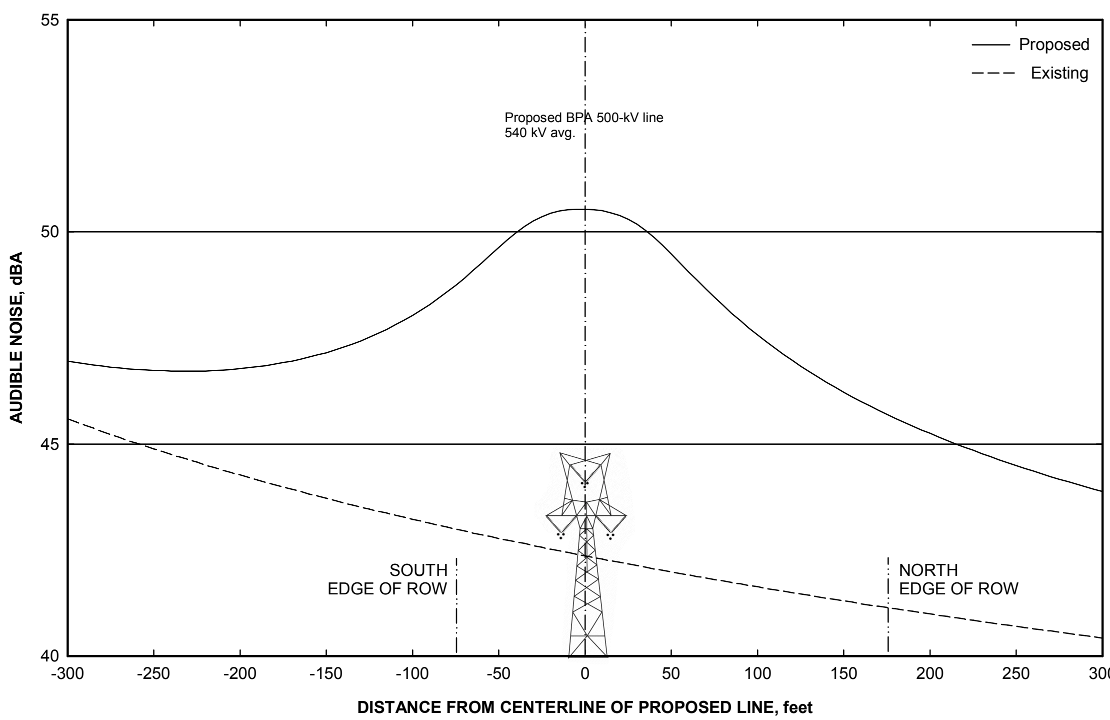
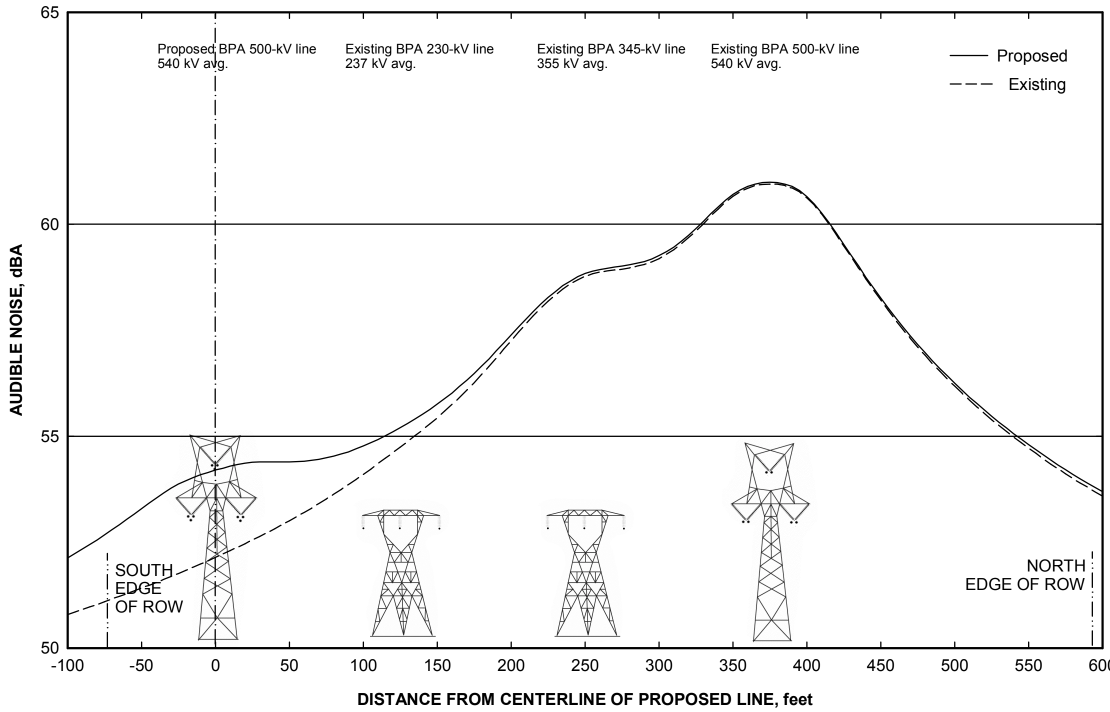


Figure 4, continued

d) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4, 125-ft. spacing)



e) Proposed line on existing towers with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4A)

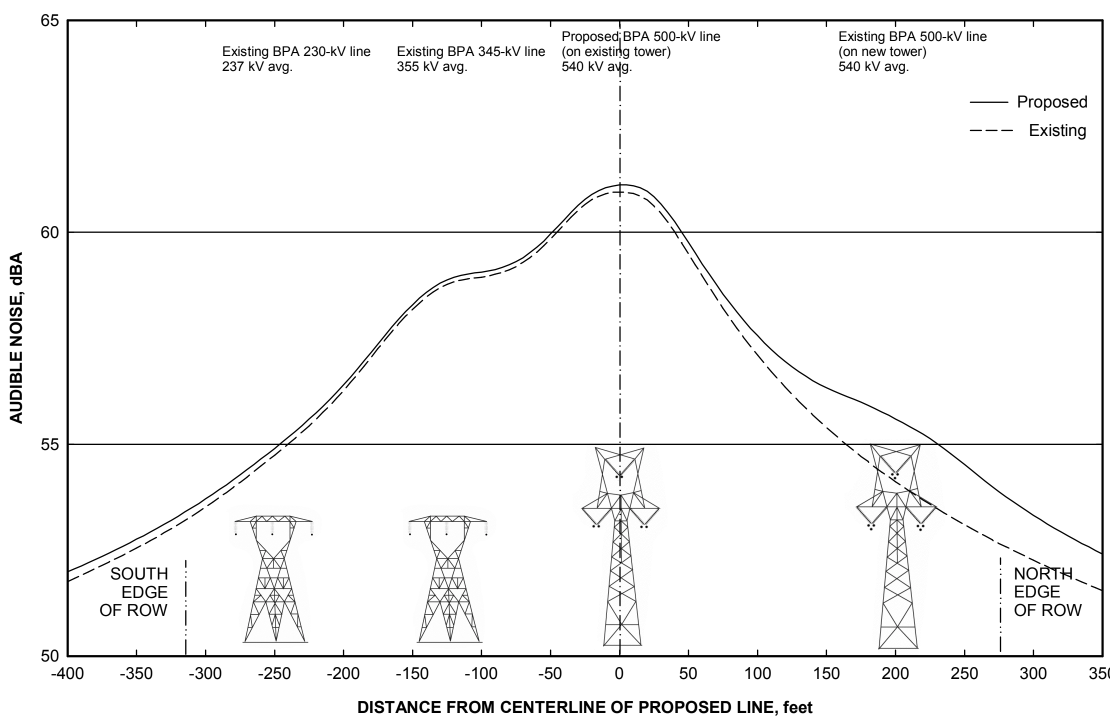


Figure 4, continued

f) Proposed line with parallel 230-kV, 345-kV, and 500-kV lines (Configuration 4B, 275-ft. spacing)